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RESEARCH AND TECHNOLOGY

ANNUAL REPORT 1986

Ames Research Center

Moffett Field, California

NASA

Introduction

This annual report illustrates selected achievements at the Ames-Moffett and Ames-Dryden sites of Ames Research Center. The contents illustrate the challenging work that has been accomplished in the past year in the areas of Engineering and Technical Services, Aerospace Systems, Flight Operations and Research, Aerophysics, and Space Research. The contents clearly demonstrate the diversity of the research activities at Ames and provide an indication of the stimulating challenges that will be met in the future.

If you desire further information on any of the Ames research and technology programs, please write to the Chief Scientist, Dr. Jack Nielsen, MS 200-1A, NASA Ames Research Center, Moffett Field, CA 94035, or call the investigator listed in the report.

William F. Ballhaus, Jr.
Director

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Aerospace Systems

Tilt-Rotor-Based Emergency Medical Services in the Caribbean Basin

An evaluation of the potential advantages of the tilt-rotor-vehicle technology for a specific emergency medical service (EMS) application has been undertaken. The feasibility of rotorcraft-based EMS in the Caribbean Basin was assessed using data on population, motor vehicles, and motor-vehicle accidents. A discrete-event Monte Carlo simulation model permitting a comparative analysis of conventional rotorcraft and the tilt-rotor aircraft as EMS vehicles was developed. This model was used to compare the relative performance of these vehicles and to evaluate the required number and location of EMS centers and rotorcraft in Puerto Rico and the Lesser Antilles.

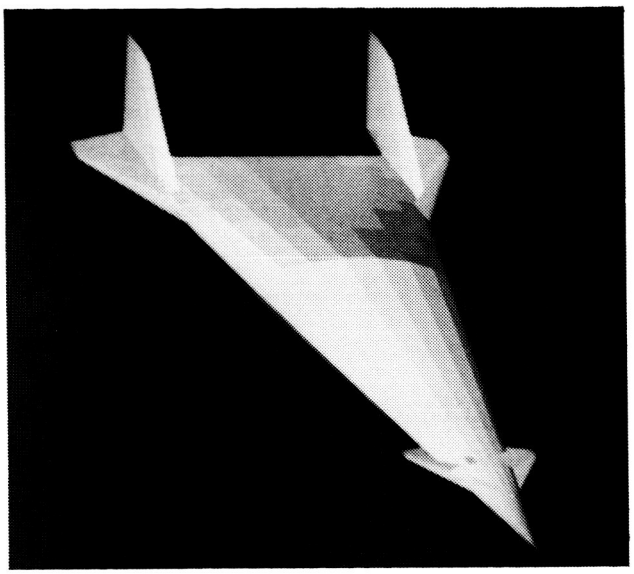
The model accepts as input data the locations and categories of hospitals, the number and capacity of helicopters at each hospital, the region in which a given percentage of accidents will occur, and other data relating to rescue time, response time, etc. The output of the program includes the average wait time before an accident victim is reached, the average rescue time before the victim is taken to the nearest appropriate hospital, the number of accident victims who were not rescued because of the lack of an available helicopter, and the number of hours per week that each helicopter spends flying.

The simulation analyses indicated that two tilt-rotor vehicles could perform more effectively for the region than three helicopters, with significantly less average rescue time and fewer out-of-range accidents. This is a generic model that can be applied to other EMS locations as well as to a broader scope of public service and commercial missions. The generic model can be executed on a personal computer.

(L. Alton, Ext. 5887)

Generalized Aircraft-Graphics System

The Advanced Plans and Programs Office (APPO) is extensively involved in aerospace-vehicles-configuration assessment and systems analysis. This effort is used to focus research and technology activities relating to aeronautical concepts, define technology benefits, and determine potential design applications. A major tool used in this effort is the conceptual-design computer code which will analyze a given aircraft configuration, mission requirements, and design constraints. Several design codes are currently in use with the capability to analyze aircraft configuration ranging from helicopters to hypersonic vehicles. The graphical display of the vehicle geometry is an important part of the overall vehicle analysis. The vehicle layout design and potential geometric design constraints can be easily assessed and design changes can be implemented.



Panel model of a blended body hypersonic aircraft

A generalized aircraft graphics system (GAG) has been developed for APPO by the Sterling Software Corp. This system allows the research engineer to input and manipulate geometric data produced by the aircraft preliminary design (PD) codes, generate a three-dimensional (3-D) model of the aircraft defined by the geometric data, and then produce either graphical output or other informational output to be used in paneling codes or elsewhere. The premodeling process inputs the geometric data provided by existing aircraft PD codes (ACSYNT, GASP, HESCOMP, VACOMP, etc.) and provides data required for modeling the aircraft. The modeling process then developes a 3-D database, which will have a standard format. The modeling process is flexible to allow the modeling of a diverse set of

objects. The postmodeling process is a set of file formatters. The data from this data file are interpreted by both 2-D and 3-D graphics programs (a graphics terminal is considered a file). Also, the data can be reformatted to be used as input to existing analysis programs (e.g., NASTRAN, PATRAN, or CFD codes).

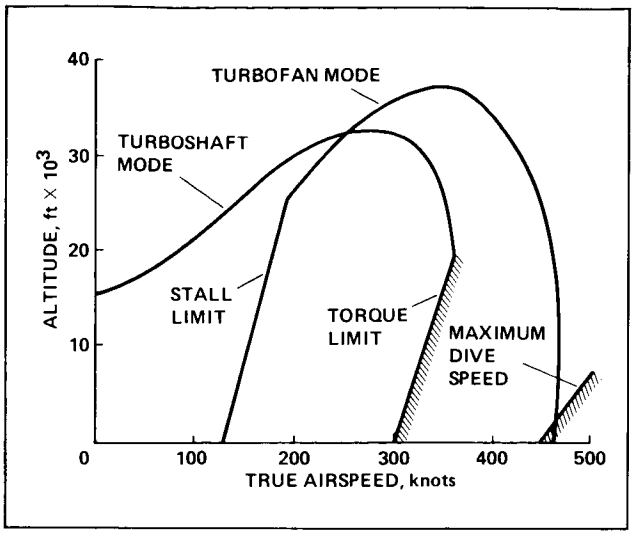
(J. Bowles, Ext. 5673)

Folding Tilt-Rotor Demonstrator Feasibility Study

Application of advanced, high-speed, rotorcraft-technology concepts hold promise for both military missions and potential civil transport applications. These rotorcraft designs will combine efficient VTOL hover capabilities with high-subsonic-speed cruise performance comparable to that of a subsonic-jet fixed-wing aircraft. This class of advanced rotorcraft utilize low disk loading for the VTOL mode, which provides efficient hover, and converts to a "high disk loading" mode for high-speed flight with the rotor no longer being used to produce forward thrust. One such concept is the folding tilt rotor (FTR), in which the hover rotor is stopped and folded for high-speed cruise operation, and a turbofan furnishes the thrust.

A joint study by Ames Research Center and Lewis Research Center has been completed. This study assesses the feasibility of modifying existing aircraft to demonstrate the FTR concept over the entire speed regime (hover, transition and conversion, high-speed flight). Study results showed that, pending availability of convertible engine designs, the speed-enhancement capability of the FTR concept could be demonstrated. Three potential candidates are considered. One candidate would use the Bell/Boeing V-22 Osprey combined with either the existing TF-34 convertible engine or a conceptual convertible engine using the torque-converter-coupled fan configuration. The second would combine the same power plants with a modified Lockheed S-3A Viking. The third FTR demonstrator aircraft studied would use the NASA/Army/Bell XV-15 airframe mated with a conceptual generic turbofan engine with a fixed-pitch fan coupled to the engine by means of a torque converter.

(J. Bowles, Ext. 5673)



S-3A FTR flight envelope with torque-converter PD 434-7 convertible engine

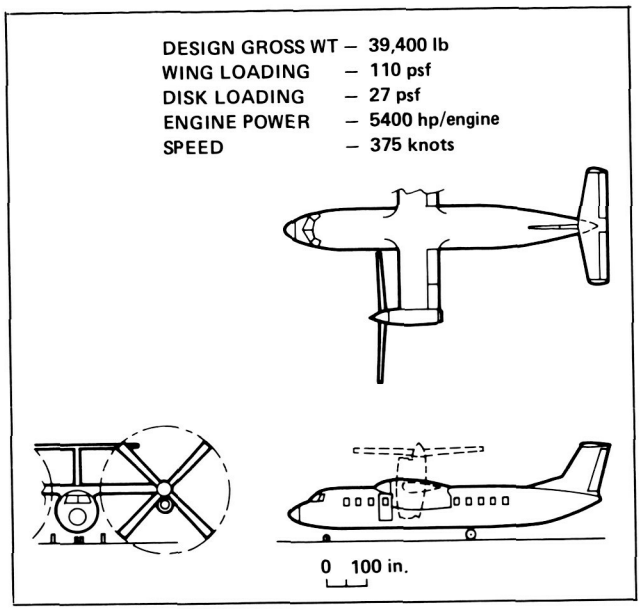
High-Speed Tilt-Rotor Feasibility Studies

The Advanced Plans and Programs Office has conducted conceptual design studies to assess the feasibility of high-speed tilt-rotor concept aircraft. These studies addressed the technology requirements needed to demonstrate sustained speed capability 100 knots and greater than existing tilt-rotor aircraft, and have resulted in enhanced productivity for advanced rotorcraft designs.

The first study assessed the design improvements of existing tilt-rotor technology necessary to provide a 400-knot cruise capability. Starting with the XV-15 and V-22 technology database, the rotor, hub, wing, and airframe designs were reoptimized for high-speed applications. The rotor design was configured for low drag at high helical tip speeds to minimize compressibility drag (with modest hover performance penalties) using advanced airfoil designs. Advanced hub designs were used to shift the whirl-flutter stability boundary to high values (affecting wing stiffness/weight requirements). Advanced 23% thick wing airfoil designs were developed to produce low wave drag at Mach 0.65. Composite structure and reduced drag configuration design concepts were also implemented. Using a conceptual design code for tilt-rotor configurations, the impact of the advanced technology concepts on two tilt-rotor designs (a 46-passenger civil

transport and an air-combat escort fighter) was determined, with results indicating feasible high-speed tilt-rotor aircraft. Maneuverability performance was also estimated.

(J. Bowles, Ext. 5673)



46-Passenger high-speed tilt-rotor transport

Tilt-Rotor Applications Study

The unprecedented success of the NASA/Army XV-15 Tilt-Rotor Research Aircraft program demonstrated the maturity of the tilt-rotor concept. Following a series of military mission-suitability demonstrations by the XV-15, an assessment of advanced vertical lift concepts was conducted to determine the best technical approach for application to the JVX, a joint services vertical lift aircraft. The tilt-rotor concept was the clear winner in that assessment and was selected for development of the JVX (which was later designated the V-22 Osprey). That program, which has entered full-scale development, will produce 552 aircraft for the Marine Corps, 50 aircraft for the Navy, 80 aircraft for the Air Force, and 231 aircraft for the Army. In addition to the basic program, the Navy is considering the procurement of 300 SV-22s for the antisubmarine warfare mission.

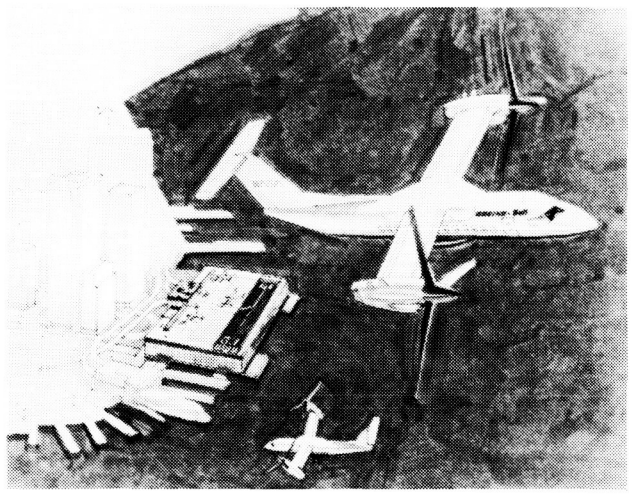
The development of the V-22, which possesses capabilities not available in any other aircraft, prompted the adminstrator of the FAA to propose to NASA and the Department of Defense that the three agencies conduct a joint study "...to assess the broader implications of the V-22 aircraft development to the nation as a whole." NASA and the DoD agreed and a joint study, managed by NASA, was initiated with the following major tasks:

1. Analysis of missions
2. Civil development of tilt-rotor aircraft
3. Technology spin-offs
4. Impact on the defense industrial base
5. Executive summary and invited forum

The study includes in-house work by NASA, the FAA, and DoD, and a contracted effort by Boeing Commerical Airplane Co. with participation by Bell Helicopter and Boeing Vertol. The contractor team has produced "first-look" designs for 10, 18, 40, and 75 passenger tilt-rotor aircraft. Inputs from potential users have been solicited, and market potentials are being evaluated. Some of the emerging applications include executive transport, commuter service, natural resource development, and emergency medical service. The operational flexibility of the aircraft offers new avenues for congestion relief in high-density air-traffic corridors, and development of third-world countries.

The study is proceeding well and is expected to be complete in the spring in 1987, with a forum tentatively scheduled for August 1987.

(T. Galloway and C. McKeithan, Ext. 6012)



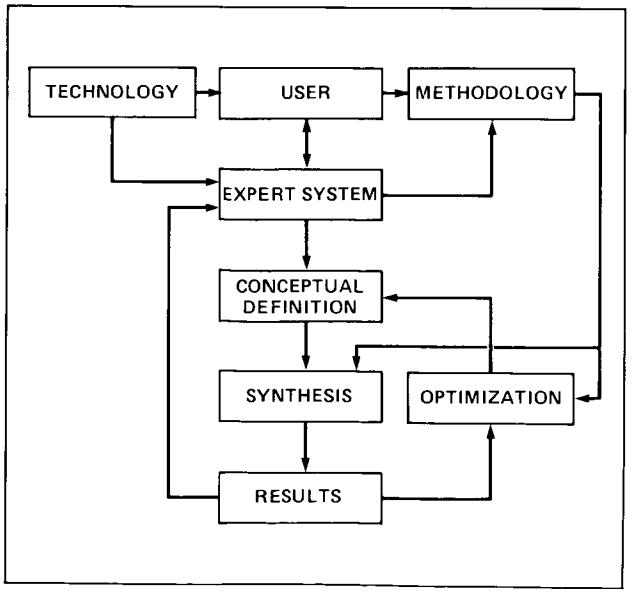
Future civil tilt-rotor in city-center transport service

Expert Systems in Aircraft Design

The challenging requirements that are evolving for future aircraft demand that each design be optimally integrated, for the penalties imposed by nonoptimal performance are significant. Classic numerical optimization algorithms have been and will continue to be important tools for aircraft designers. These methods, however, are limited to certain categories of aircraft design variables, leaving the remainder to be determined by the user. A method that makes use of knowledge-based expert systems offers the potential for aiding the conceptual design process in a way that is similar to that of numerical optimization, except that it would address discrete, discontinuous, abstract, or any other unoptimized aspect of vehicle design and integration. Other unique capabilities such as automatic discovery and learning in design may also be achievable in the near term.

A framework for the integration of knowledge-based expert systems has been identified and a prototype is evolving. This work indicates that there are significant benefits to be gained in certain design activities, and that there are some tasks not well suited to expert systems. Two areas are being evaluated: assistance in code input/ouput, and enhanced parameters optimization (shown schematically in the figure).

(G. Kidwell, Ext. 5886)



Design synthesis using both numerical optimization and expert systems

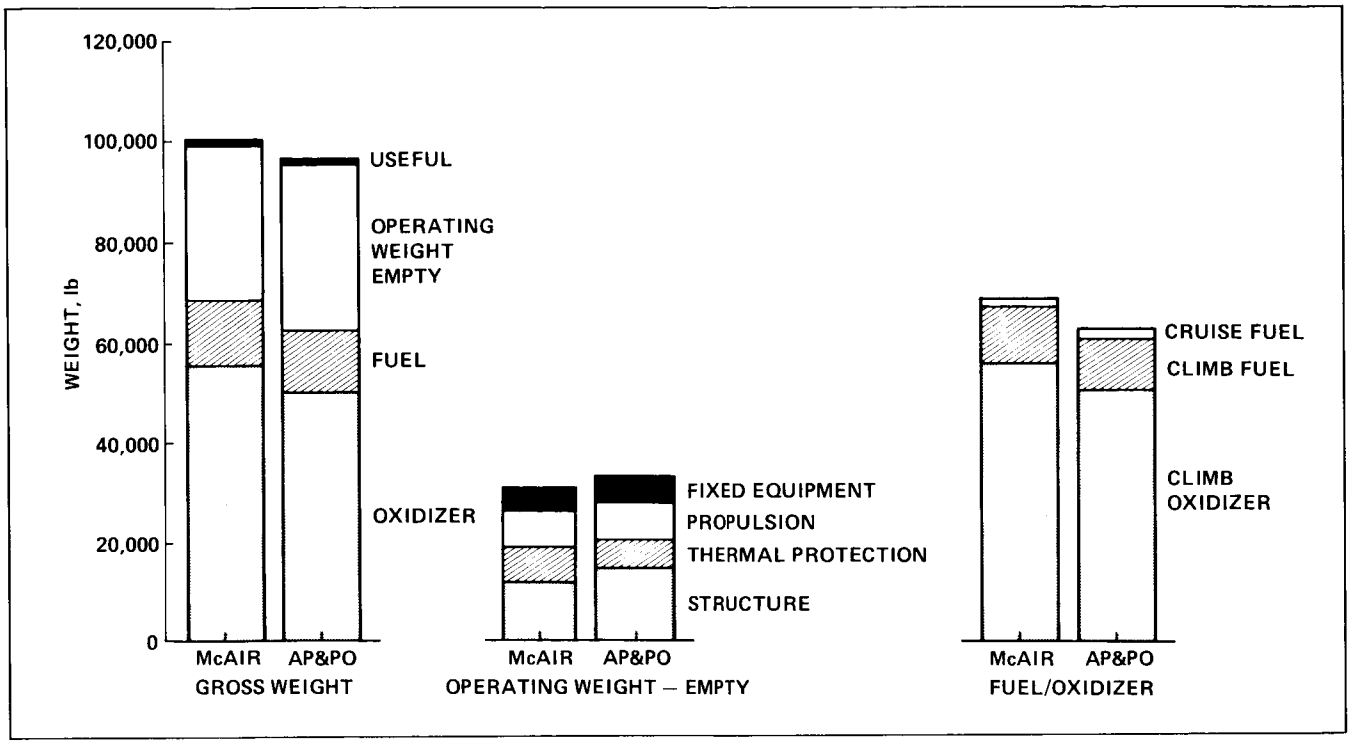
Hypersonic Aircraft Conceptual Design

Technological advancements in materials, propulsion, and computers have led to a strong national interest in a single-stage hypersonic aircraft capable of operation from conventional runways, such as in the national aerospace plane (NASP) program. The relatively small database on configuration performance requires that the many alternative vehicle concepts be carefully evaluated so that the optimal candidate is identified. To enable this to be done quickly, a previously developed conceptual design synthesis computer program for hypersonic aircraft has been upgraded and enhanced. This synthesis code was extensively used at Ames from 1963 to 1974 to guide research and design efforts on cruise, launch, and research vehicles.

As a synthesis program, the various design and analysis modules are linked to each other and to executive functions that close the vehicle design for weight, volume, and other constraints. Currently, only all-body configurations are treated (although a wing/body capability is nearing completion). There are many options available to the user in the areas of structures, thermal protection, propulsion systems, and mission profile. Also, numerical optimization is available to automatically determine the optimum design variable values necessary to minimize an objective function.

The program has been validated by correlating results with those of a hypersonic facilities study performed 20 yr ago. By modeling these configurations (which were thoroughly evaluated by the contractor), the accuracy of the conceptual-level methods were compared directly in all vehicle areas. The results indicated that both the absolute values and the sensitivity trends were generally closely approximated. A parametric study of a Mach 12-16 blended body research aircraft and a potential hypersonic cruise vehicle for the "Orient Express" mission have been completed.

(G. Kidwell and J. Bowles, Ext. 5886/5673)



HY-FAC/HST weight correlation

Modern Airship Flight Data

In-flight dynamic response data on a full-scale "modern technology" airship have been obtained and analyzed. The report on this effort culminates a joint program in which Ames Research Center participated with the U.S. Navy and Coast Guard in the Patrol Airship Concept Evaluation (PACE) program staring in 1983. A modern technology airship manufactured in Britain (the Skyship 500) was used in the program. The objective of the program was to evaluate the application of modern technology airships to long-duration patrol surveillance and other missions. Another objective of the program was to obtain response data of a type and quality suitable for validating the NASA HYBRDS code. The Navy requested NASA's expertise in the flight charactersitics evaluation and flight-data-acquisition phase of the program.

Personnel from Ames Research Center and Systems Technology Incorporated (STI, under contract to Ames) instrumented the vehicle and conducted the evaluation with the active participation of an Ames research pilot. The flight data were obtained on the Skyship 500 nonrigid airship design. Its features include lightweight envelope materials: Kevlar-epoxy gondola, and extensive use of composite panels; vectorable ducted-fan thrustors, including reverse pitch; and fixed-wing aircraft-type controls and displays. Envelope volume was 181,200 ft^3 with a length of 164 ft, and a diam of 61 ft. Useful load was 1.9 tons.

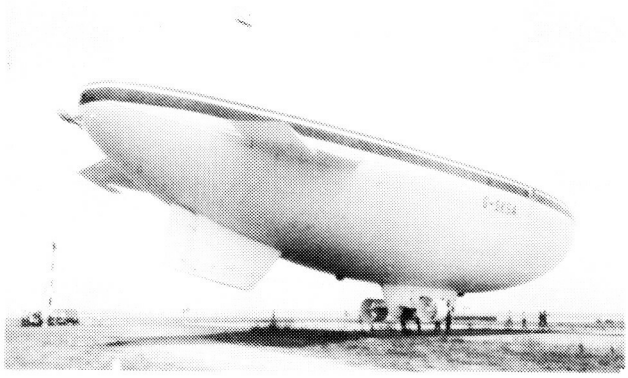
STI's analysis of the performance data, which included measured thrust, showed drag levels agreeing with predicted data (i.e., an equivalent wetted-area drag coefficient of 0.00545). Thrust required in steady turns was significantly higher than in straight flight (e.g., drag at turn rates of 8°/sec were three times the zero turn values at a speed of 30 knots).

Frequency-sweep data were analyzed by STI using Fast-Fourier-Transform techniques and describing functions were generated for various responses to control inputs. Results showed good data repeatability indicating that the data are reliable. Various dynamic modes were clearly defined, and all the classic rigid-body modes of an airship were identified as were some higher-

frequency, flexible, cab-on-hull modes in pitch and roll. Apparent mass effects on the dynamic center of rotation in pitch were identified and analyzed. The data showed that this airship is slightly unstable in level cruise flight at small yaw angles, but is stable in turning flight.

The NASA evaluation pilot found the airship to be well behaved and an "agreeable" ship to fly in the smooth atmospheric conditions experienced during the test period. Turning performance was impressive considering the size of the ship. Full rudder control produced a very tight turn radius and, because of the pendulum stability, the gondola trims neatly under the turning envelope. Thrust-vectoring capability enhanced the takeoff, climb, and landing-approach maneuvers by giving the pilot increased control over flightpath angle and climb/descent rates.

(R. Kurkowski and P. Gelhausen, Ext. 6569/6276)



Skyship 500

U.S./Canada Ejector-Technology Program

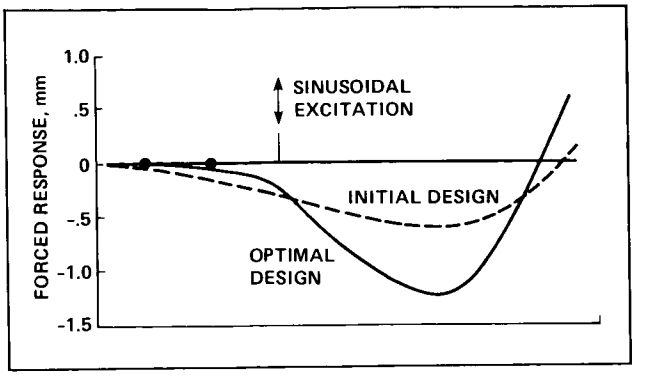
NASA and the Canadian Department of Regional Industrial Expansion signed a Letter of Agreement in October 1985 to conduct an ejector-technology program, which is to fabricate and test a 0.9-scale model of the General Dynamic design E-7 STOVL aircraft. The model is being fabricated by de Havilland Aircraft of Canada, Ltd., and will be powered by a Rolls Royce Spey 801-SF engine. The aircraft thrust in hover will be generated by a chordwise ejector on either side of the fuselage in the wing-root area fed by the engine fan air at a pressure ratio of approximately 3.0 and aft engine core thrust which is vectored vertically. In the cruise mode, the fan air is directed aft through a second nozzle, and the ejector areas are closed by fairing doors. The core thrust is vectored horizontally. The aircraft is designed to have a supersonic dash capability.

Components of the aircraft model propulsion system are scheduled to be calibrated and tested on the powered lift test rig at Lewis Research Center beginning in October 1986. In the fall of 1987, the fully assembled model will be tested on the Outdoor Aerodynamic Research Facility, and in the spring of 1988, it will be tested in the 40- by 80-Foot Wind Tunnel at Ames Research Center. Simulation investigations of the aircraft concept will be conducted at Ames following the generation of the mathematical model, which will be predicated on the results of the wind tunnel investigation.

(B. Lampkin, Ext. 6039)

Tuning Structural Vibration

A computer program was developed to modify structural design parameters automatically to control steady-state vibration levels. This was made possible by integrating a general finite-element code (NASTRAN), a general optimization code (CONMIN), and a set of FORTRAN programs to implement approximation concepts for structural optimization. When this system is used, the static and dynamic structural responses can be tuned simultaneously to achieve prescribed objectives by stiffness and mass redistribution. For example, minimizing vibratory amplitudes at given locations while satisfying strength and stiffness requirements or maximizing natural vibration frequencies or specified modes under constraints imposed on structural weight, may be investigated. Dynamic responses are usually difficult to handle intuitively, and frequently the results obtained by automated methods provide innovative suggestions to designers. The impedance-matrix approach used in this development turned out to be an effective technique to turn a multiple number of modes/shapes simultaneously. The modal participation factors and the modal amplification factors are key parameters to indicate how the



Steady-state vibration amplitude

mode shapes were tuned to achieve the specified objectives. The method accommodates structural and viscous damping effects.

Since the steady-state dynamic responses are important criteria for the design of a structural system with rotating parts of constant revolutions per minute, there are a wide range of applications. One of the important subjects is helicopter airframe vibration problems, for which the vibratory load of a fixed frequency (rotating revolutions per minute times the number of blades) is the dominant excitation force. The example shown in the figure represents an AHIG stick model which was studied extensively in the past. The problem is to reduce the steady-state vibration level at the pilot seat (node 8) and at the gunner (node 5) simultaneously. It is not possible to nullify the vibration levels at two distinct points simultaneously, but with automated design capability, quantitative trade-off studies can be performed. Another important application was recognized in the design of support structures of rotating machinery. It is necessary to reduce vibration induced by unbalanced forces transmitted to the foundation. A practical scale problem was solved by this system and the vibratory forces at the foundation were reduced to less than 50% of the best design achieved by experienced designers using trial and error methods.

(H. Miura, Ext. 5888)

Public-Service Helicopter-Technology Needs Assessment

Helicopters are playing important roles in such public service activities as emergency medical service (EMS), search and rescue, law enforcement, and public safety and disaster relief. Recognizing the national needs, both for improved public-service helicopters and increased competitiveness of the U.S. helicopter industry in the world marketplace, NASA sponsored a program to accelerate helicopter and onboard equipment development and transfer through the U.S. industry to public-service users. The first phase of this program has been completed wherein Sikorsky Aircraft, Boeing Vertol, Bell Helicopter and Hughes Helicopter each conducted studies of 1) a definition of the public-service user operations and markets, 2) assessed the technology needs, 3) assessed potential national benefits, and 4) identified actions needed to realize full potential of public-service helicopter service and market.

Some key study results were that 4000 new public-service helicopters would be needed by the year 2000, principally in the 8,000-lb gross-weight class. The EMS market requirement alone is 400-500 helicopters with an acquisition cost of $1 billion, and an annual operating cost of $720 million. For safety reasons there is a strong trend to twin turbine equipment.

Some technology utilization-type needs which were identified were: cockpit display integration, electronic flight control, omni-directional airspeed, etc. Identified near-term research and technology (R & T) needs were: zero visibility IFR systems, on-board aircraft condition monitoring, main-rotor deicing, higher harmonic control, full-authority digital engine control, energy absorbent structure and seat, and integrated medevac helicopter design criteria development. Far-term R & T needs include advanced cockpit/crew station integration, advanced airframe composites, helicopter noise prediction and reduction, and aerodynamically efficient rotors.

Potential societal national benefits were assessed to be $90 billion/yr. By mission, the breakdown in billions is: EMS, 83; public safety and law enforcement, 5; search and rescue, 2; and fire fighting, 0.3. Other benefits include: 30 to 80% reduced accident-response time, 50% mortality reduction for trauma and neonates, EMS service to areas where none now exists,

improved evacuation from remote or inaccessible areas, and increased utilization of critical-care facilities and other specialized centers.

Some key barriers to realizing the full potential of public-service helicopters and their market are high initial and operating costs, lack of public acceptance of the helicopter (which is strongly influenced by noise), and high insurance rates.

The results of these contract studies are acting as catalysts to stimulate application of existing technology and as drivers for near-and far-term rotorcraft and related systems research and technology.

(J. Zuk, Ext. 6568)

Aviation Technology Applicable for Developing Countries

An analysis of aviation technologies which would be useful for formulation of aviation or development plans to the year 2000 for the emerging countries of the world has been completed. The Caribbean Basin was used as a specific application. Aviation technology was organized in the following categories: current technology in the region, applicable technology used in other regions, significant trends in technology, and technology issues regarding developing regions. The categories covered under the significant trends in technology section were: next generation conventional take-off and landing (CTOL) aircraft, general aviation aircraft, rotorcraft applications, rotorcraft technology, lighter than air, used-aircraft upgrading, and computer/satellite advances.

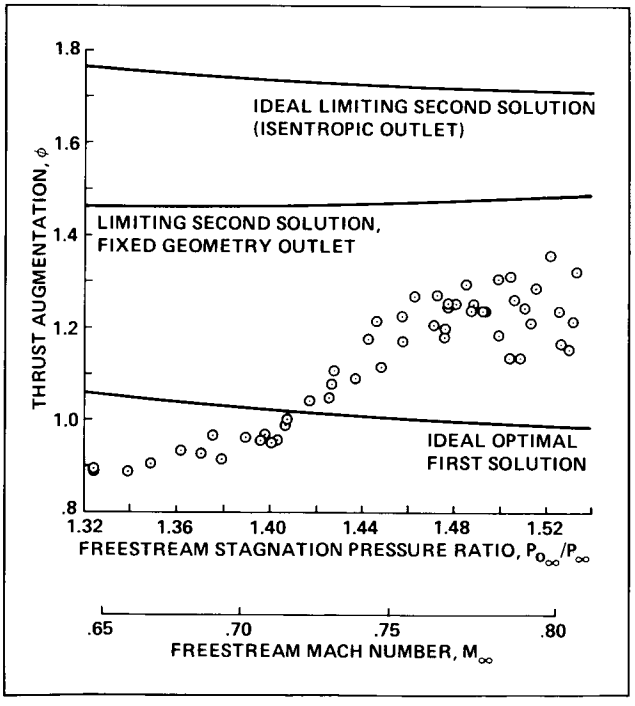
The rapid growth of aviation technology, and passenger and cargo traffic that has occurred in the past is projected as likely to reoccur in the future as well. These aviation technologies, if planned for and utilized properly in these developing regions, offer the possibility of "leap frogging" current technology to arrive in the 21st century without many of the major costs involved in present technology, such as extensive air-traffic control ground infrastructure, new and extended airports, and road, rail, port, and communication systems in remote areas.

The next generation transport aircraft, with improved infrastructure and management methods, will provide lower cost air transportation to the region from the U.S. and the rest of the world. The new short-haul air transportation capability, if looked at from an overall systems and intermodal viewpoint, can offer many unique economic development opportunities. Satellite technology will enable rapid, economical capabilities in many areas such as navigation, communications, weather forecasting, training, and maintenance assistance.

(J. Zuk and L. Alton, Ext. 6012)

High-Speed Thrust Augmenting Ejector

Experimental studies were conducted at the Flight Dynamics Research Corp. to investigate the flow and the performance of thrust-augmenting ejectors for flight Mach numbers in the ranges 0.5 to 0.8, primary air stagnation pressure ratios up to 8.27,and primary air stagnation temperatures up to 1250°F. The experiment verified the existence of the second-solution ejector flow, where the flow, after complete mixing, is supersonic. For a simple, constant-area ejector, thrust augmentation in excess of 1.2 was demonstrated for both hot and cold primary jets as shown in the attached figure. While the



Ejector performance, $P_{op}/P_\infty = 7.65$, $\alpha_* = 30.2$, $T_{op} = T_\infty$

ejector performed better than the ideal optimal first solution or subsonic ejector, further research is needed to realize the full potential of the second-solution ejector, with suitable area variation needed for highest augmentation ratios.

(V. Corsiglia, Ext. 6677)

Full-Scale Ground Effects of a Twin Jet VSTOL Aircraft

One of the major areas of uncertainty still remaining in the development of multijet, medium, disk-loaded VSTOL aircraft is the influence of propulsion-induced aerodynamics in the vicinity of the ground — ground effects (GE). The propulsion-induced aerodynamics are directly related to (and in fact the cause of) the four major problem areas of ground effects as they relate to aircraft design. The four areas are generally referred to as suck-down, ground erosion, upwash fountain impingement on the aircraft, and inlet reingestion of hot gas or debris. To obtain answers to these questions for a twin-engine, tilting-nacelle, turbofan VSTOL aircraft, a series of large-scale wind tunnel and hover investigations were conducted using a full-scale version of Grumman Aerospace Corp. design 698-411 (GAC-698) VSTOL aircraft shown in the figure. The funding support for these programs is provided jointly by NASA, the Navy, and Grumman Aerospace Corp.

Experimental data in the form of pressure distributions on the ground beneath the aircraft and on the undersurface of the aircraft's fuselage were measured. The integrals of these distributions were compared with measured model forces, both for the total model and for isolated nacelles, (i.e., gross thrust). Typical pressure distributions on the ground plane were also measured. The ground-plane pressures agree well with predictions made by simple inviscid computer programs and small-scale experimental studies, but near-field pressure distributions are more complex owing to the presence of the control vanes and the coannular flowing jet exhaust. The fuselage pressures show considerable differences from what was predicted, particularly the narrow extent of the fountain impingement and the large nonsymmetric (even during symmetric thrust and control conditions) regions of surface pressure below ambient pressure. These regions of nonsymmetry contribute significant rolling moments to the aircraft.

Analysis of the results show that the propulsion-induced aerodynamics cause changes in control effectiveness, lift, upsetting moments, ground impingement and hot gas reingestion. Some of the flow-field details are shown for jet-impingement, wall-jet formation and development, and the upwash fountain.

(M. Dudley and J. Eshleman, Ext. 5046)

Twin tilt nacelle, subsonic tactical VSTOL concept, undergoing hover testing at the NFAC outdoor facility

Lift Distributions for the Three-Dimensional Steady Blade-Vortex Interaction

Blade-vortex interactions occur as the tip vortex shed by a lifting rotor blade passes near a following blade, and are inherent to rotor operation in both hover and forward flight. Such interactions directly affect both the aerodynamic and acoustic fields surrounding the rotor.

An experiment study of the three-dimensional (3-D) steady blade vortex interaction has been conducted in the Ames Research Center 7- by 10-Foot Wind Tunnel. A semispan rotor blade configuration was used. An adjustable vortex-generating airfoil mounted upstream of the rotor blade provided a tip vortex of known strength which could be accurately positioned relative to the rotor blade.

Aerodynamic data were obtained nonintrusively with a 3-D laser velocimeter (LV). Velocity data were integrated to obtain the bound vorticity, and to provide a means of nonintrusively measuring the rotor blade lift distribution with high spatial resolution and versatility. Mean velocity data showing the spatial 3-D velocity field were obtained, along with velocity grid and vortex circulation data which characterized the incident vortex. Parametric variations of vortex strength, vortex position, and blade angle of attack were examined. Total lift measurements obtained from internal strain gage balance provided experimental frequency.

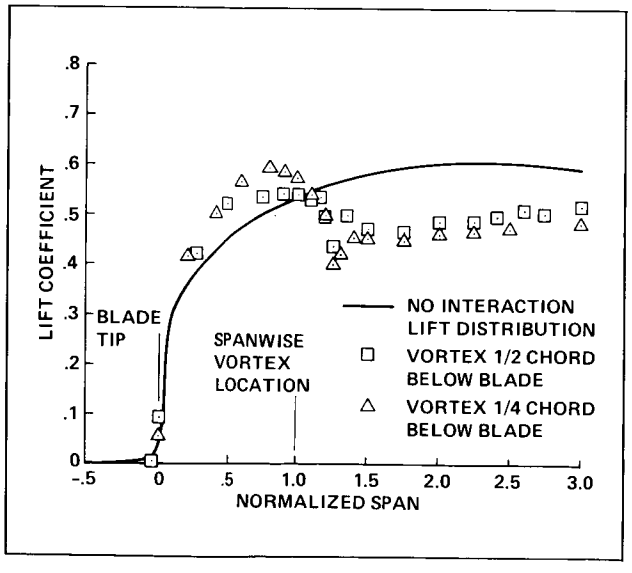
Lift distribution data show the expected trends of increased lift outboard of the vortex center, where the effective angle of attack is increased by upwash from the vortex, and decreased lift inboard of the vortex, for the opposite reason. Reasonable agreement was observed in comparisons of total blade lift values obtained from LV and balance data. These data indicate a slight loss of total lift for each of the interaction cases when compared to the interaction-free baseline. This experimental quantification of the aerodynamic field arising from the 3-D steady blade vortex interaction provides a clearer view of the magnitude and character of the interaction as well as a basis for the evaluation of analytical work directed at the prediction of such flows.

(S. Dunagan, Ext. 6653)

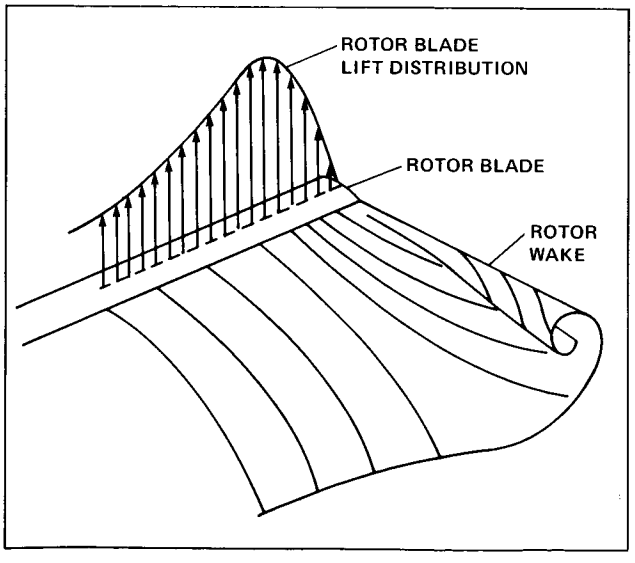
Isolated Rotor Hover Performance Analysis

A new analytical method to predict the hover performance of an isolated rotor is being developed by Continuum Dynamics, Inc., under a contract with Ames Research Center. The analysis will predict the detailed blade loading, wake geometry, thrust, and power characteristics of an arbitrary rotor design.

The analysis is being developed using a rigorous model of the fluid dynamics of the rotor and rotor wake to avoid the empiricisms that have been used in previous analyses. One of the key features of the method is the manner in which the rotor-wake geometry is calculated. The wake geometry is found using a relaxation procedure instead of the traditional time-stepping approach. The relaxation procedure avoids the stability problems and long computer times that have plagued the time-stepping methods in the past. The rotor-blade aerodynamics are computed using a vortex-lattice/lifting-surface approach, and the blade and wake aerodynamics are relaxed simultaneously. This procedure eliminates the need to iterate between the blade and wake solutions. The accuracy of the method is also enhanced by the use of previously developed curved vortex elements. These curved vortex elements more closely follow the geometry of the rotor-tip vortices than they do the traditional straight-line



Lift distributions on a rotor blade experiencing blade/vortex interaction



Rotor-wake model with curved vortex elements

vortex elements, and thereby provide improved accuracy with reduced computer time. Current research efforts are focusing on the development of an accurate and efficient model of the inboard vortex sheet and on a rigorous model of the far wake.

(F. Felker, Ext. 6096)

Rotor/Wing Aerodynamic Interactions in Hover

Rotor/wing aerodynamic interactions have a large effect on the hover performance of tilt-rotor aircraft and compound helicopters. An experimental program is under way to investigate these interactions and to evaluate the effect of changes in rotor/wing geometry.

A small-scale experiment was conducted to measure the aerodynamic forces on a wing in the wake of a hovering rotor. Two wings with identical chord and span were used in this investigation. One had a NACA 23015 airfoil with a 25% chord plain flap. The second wing (circulation control wing) had an airfoil similar to those used on the X-wing rotor, with blowing slots in the leading and trailing edges. The upper-surface-blowing slots were intended to reduce or eliminate flow separation at the wing leading and trailing edges. The rotor was a 1/6-scale model of the S-76 rotor system.

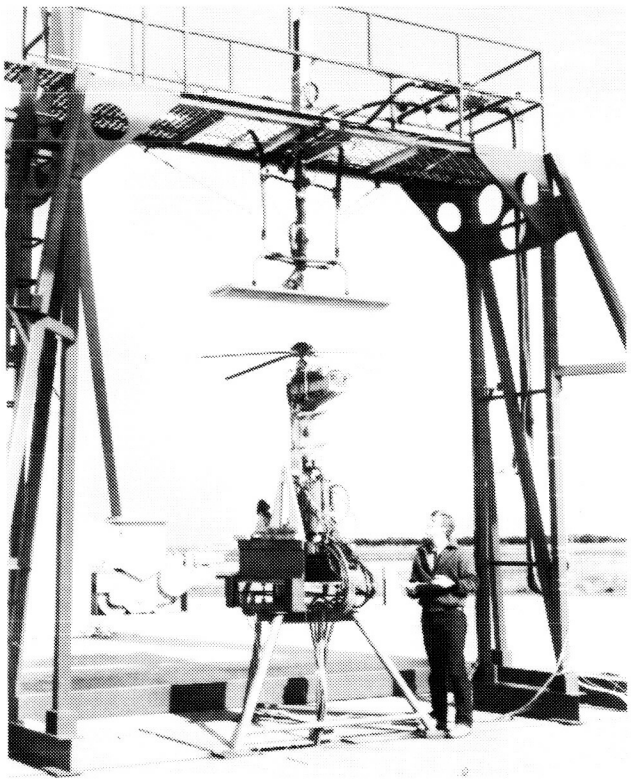
Geometry variations that were tested with the 23015 wing included the wing flap angle, wing incidence angle, rotor rotation direction, vertical distance between the rotor and wing, configurations with the rotor axis at the tip of the wing (representative of tilt-rotor aircraft), and configurations with the rotor axis at the center of the wing (representative of compound helicopters). The data showed that the download generally decreased with increasing flap deflection, and as the rotor-to-wing separation distance was increased. It was found that download can be reduced 25% for the configuration tested by reversing the rotor rotation relative to that on the XV-15 aircraft.

Parameter variations that were investigated using the circulation control wing included blowing-slot height, blowing pressure ratio, wing incidence angle, and the number of blowing slots. The decrease in download obtained with the upper-surface blowing ranged from 54% at low-rotor-thrust coefficients to 25% at high-rotor-thrust coefficients. The blowing pressure ratio had a significant effect on the wing download; the slot height had very little effect.

Using the optimum combination of trailing-edge flaps, leading-edge blowing, wing-incidence angle, and rotor rotation direction, the download on the XV-15 tilt-rotor research aircraft could be reduced from the present 12% of rotor thrust to 8%. This increase in hover efficiency would have many benefits for tilt-rotor aircraft, including higher payload, longer range, and increased maneuverability.

Current work is examining the trade-offs involved in using the upper-surface blowing wing on a tilt-rotor aircraft. These trade-offs include compressor weight and rotor power lost to drive the compressor as well as the potential for decreased wing area and lower structural weight. Future tests will evaluate the effect on download of wing airfoil-section geometry, various wing leading- and trailing-edge devices, and various blowing-slot locations.

(F. Felker and J. Light, Ext. 6096)



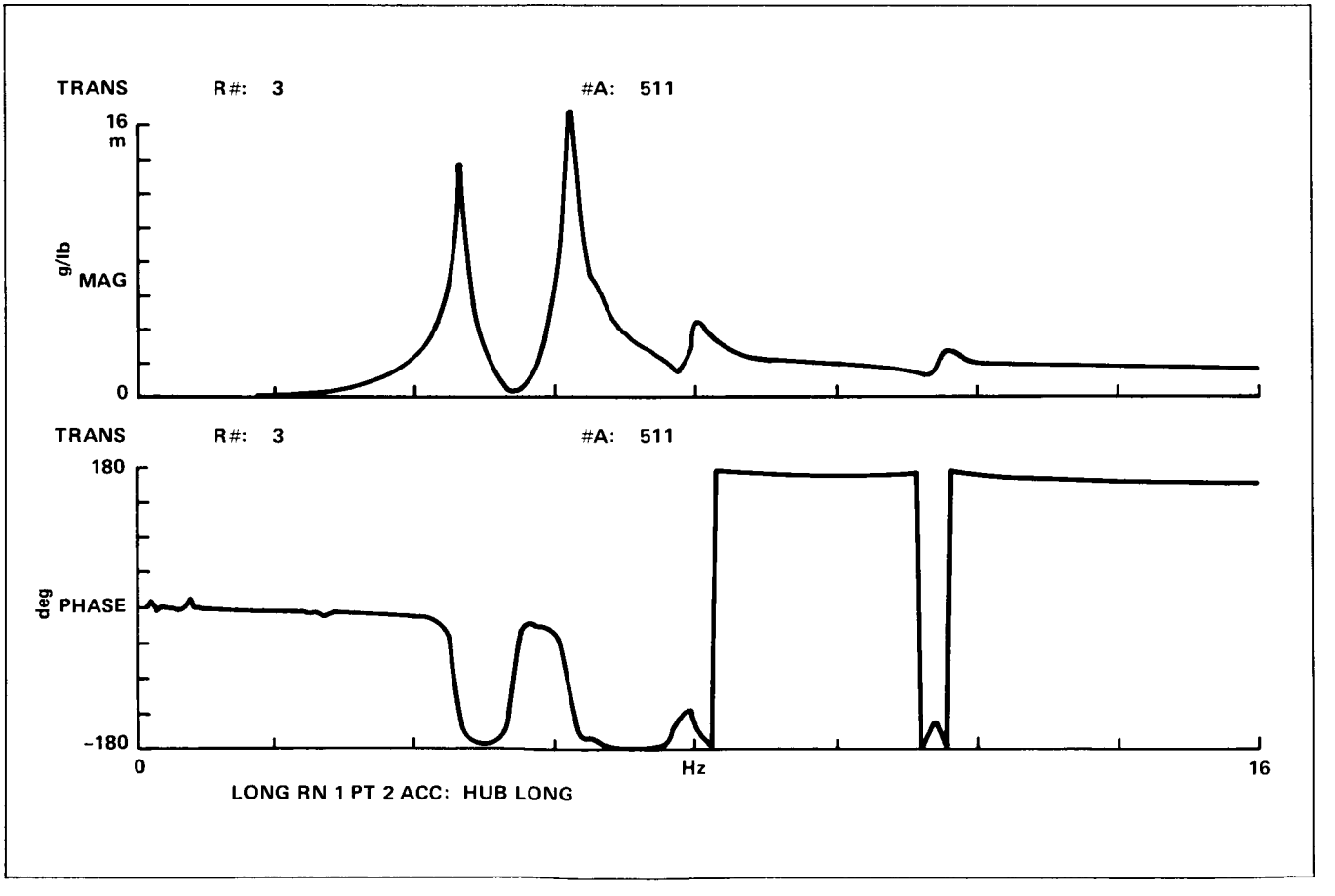
Small-scale test of rotor/wing aerodynamic interactions in hover

Coupled Rotor/Support Dynamics of a Hingeless Rotor System

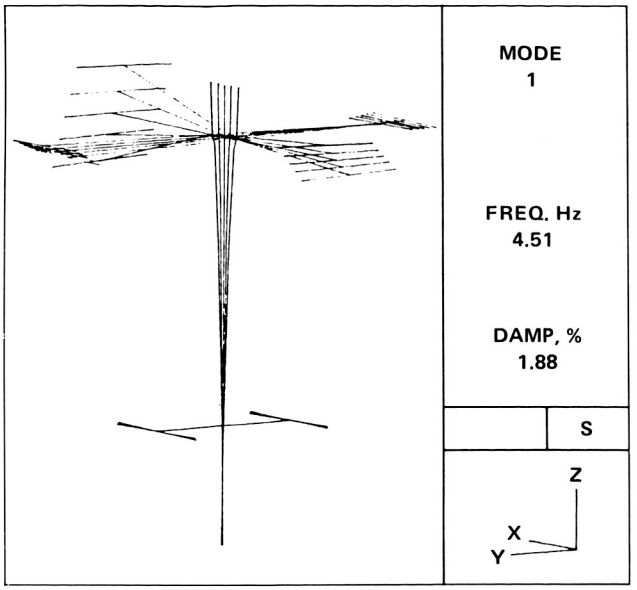
The aeroelastic stability of a rotor system is critical to successful wind tunnel testing. Careful attention must be given to pretest stability predictions to ensure adequate damping for the rotor/support system, and to identify potential, destabilizing, aeroelastic couplings. An aeroelastic coupling unique to the Bell 412 soft in-plane rotor system is its pylon-mast/swashplate coupling. In early flight tests of the 412, Bell attributed a hover instability to this coupling. This coupling is dependent upon how stiffly the pylon is mounted to the wing tunnel test stand (and rotor mast flexibility) because the control actuators are rigidly attached to the wind tunnel test stand.

Experimental and analytical investigations were made to understand this coupling, and to predict the aeroelastic stability of the Bell 412 rotor system mounted on the Ames Research Center model 576 test stand in the 40- by 80-Foot Wind Tunnel. In addition, an experimental program was undertaken to quantify the characteristics of the 412 rotor system mounted on the 576 test stand. This program consisted of a shake test of the test module with two transmission mount stiffnesses. The goal of testing two sets of mounts was to identify and understand the source of the pylon-mast/swashplate coupling more completely as well as to provide estimates of pylon-mast modal mass and damping. The figures provide typical results, including frequency-response measurements and mode shapes, and the 412/576 test stand hardware used in the experimental setup. The analytical investigation was initiated to explain the basic physics of this type of rotor/body configuration. This analysis utilizes a math model which incorporates rigid blade motion (flap and lag with noncoincident hinges), rigid body motion (pitch and roll), body/swashplate coupling, and the aerodynamics of hover (two-dimensional strip theory and dynamic inflow).

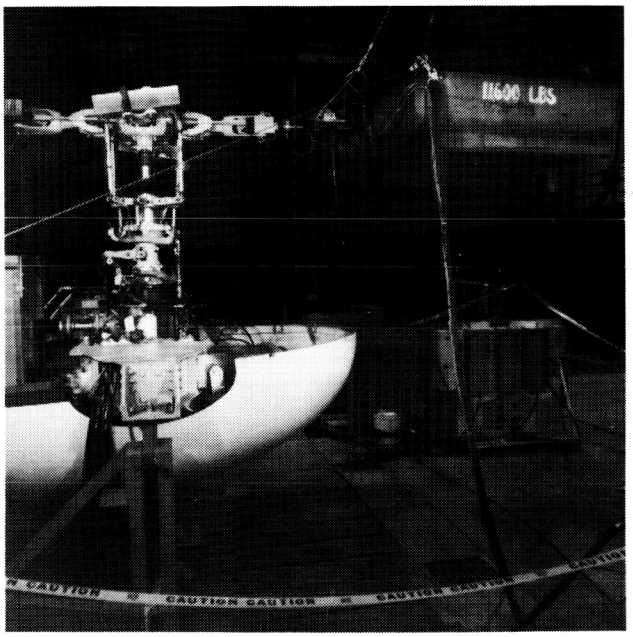
(T. Graham, Ext. 5044)



Transfer function — longitudinal shaking, hub response



Fundamental mode — mode shape, longitudinal shaking



412/576 test stand — experimental setup

Tunnel Utilization Trainer with Operating Rotor

The safe operation of a full-scale helicopter rotor in the 40- by 80-Foot Wind Tunnel requires the coordinated efforts of many test personnel, including engineers and tunnel and rotor operators. Training is desirable in correct operating procedures and responses to emergency situations. A real-time simulator has been developed to provide this training in the operation of a full-scale rotor during research testing. The simulator hardware consists of consoles with appearance and function similar to those in the 40- by 80-Foot Wind Tunnel control room.

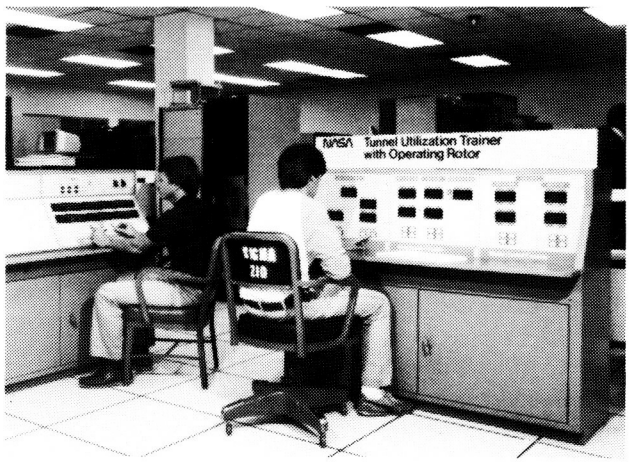
The simulation software incorporates equations which model the wind tunnel, rotor controls, and rotor motions. The rotor model is an existing blade-element model of the UH-60 Blackhawk rotor. The modeled wind tunnel elements are restricted to the main features relevant to a rotor test: rotor motor controls, model support controls and tunnel fan controls. Additional software is included to simulate failures and to drive the displays.

The results from previous validation testing had indicated degraded rotor flapping response at wind tunnel speeds above 80 knots for typical rotor operating conditions. The cause of this problem was suspected to be signal aliasing caused by the insufficient computational speed of the Sigma IX computer on which the simulation was run. This problem was investigated using a technique called time scaling that simulates running the program code on a faster computer. First, the flapping data obtained from time-scaled runs were compared to data from a wind tunnel test of a full-scale rotor as a means of validation. It was found that the flapping trends from the time-scaled TUTOR runs compared well with test data. Later, comparison of data using the time-scaling technique with data obtained in real time indicated that computational speed was indeed a problem. The TUTOR project is being implemented on a significantly faster computer, the CDC 7600.

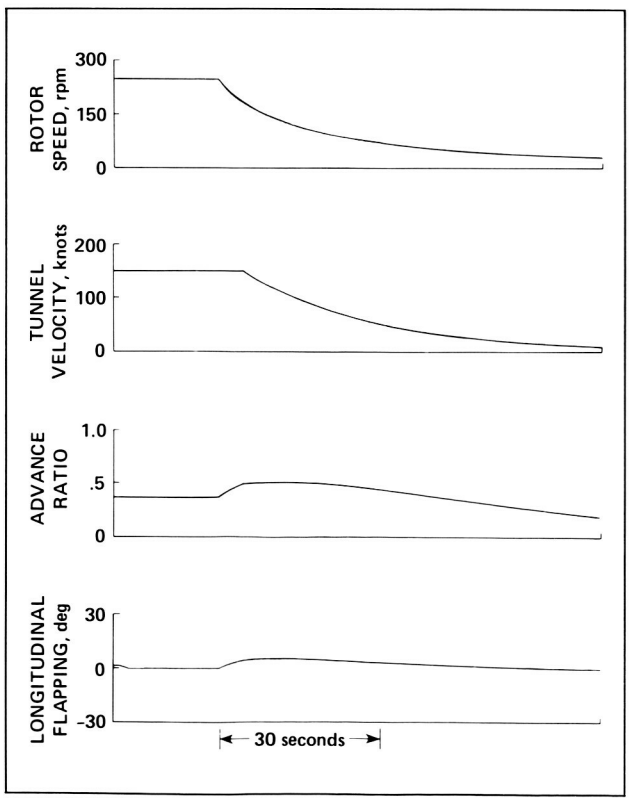
Other aspects of the simulation relevant to training are being investigated, such as decay of rotor speed after a loss of drive-motor power, emergency stop of the wind tunnel, and operation of the rotor through use of individual actuators. In particular, the wind tunnel model will be modified as necessary with information from the integrated systems test of the 40- by 80-Foot Wind Tunnel.

Training sessions began on the simulator in November 1986 so that crews may be trained for the first rotor test in the 40- by 80-Foot Wind Tunnel, presently scheduled for January 1987. Existing operational procedures are now being reviewed for applicability to TUTOR training, and a training method plan is being developed.

(D. Graham and R. Stroub, Ext. 6976/6732)



General view of the TUTOR simulator in the Ames Simulation Laboratory



Emergency response, rotor drive motor failure followed by tunnel emergency stop

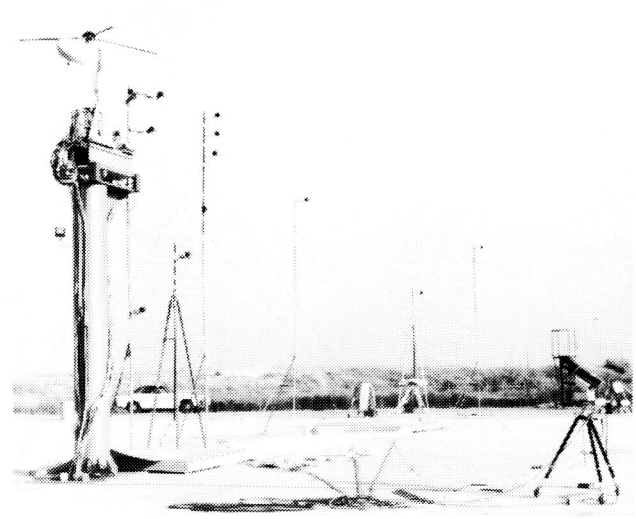
Active Controls of Rotorcraft Dynamics

Many rotorcraft dynamic phenomena involving vibration and harmonic loading can be modified or eliminated using high-speed, active control of rotor-blade pitch. Investigations of several promising active-control concepts have been initiated.

In the past year, a model-scale hover test to determine the ability of the multicycle control computer system (MCCS) to control the high-speed actuators of the rotor test rig (RTR) was completed at the Ames Research Center Outdoor Aerodynamic Research Facility. The MCCS is a general-purpose, high-speed controller which can be programmed to implement a variety of control algorithms. This test successfully demonstrated that the MCCS can safely control the high-speed actuators on the RTR. Although the computer control system functioned well, the actuators on the RTR had lower than expected frequency response characteristics.

The use of sensors located in the rotating system as a feedback source for control algorithms was also investigated during this test. A blade-root-mounted accelerometer was used to measure the rigid blade flap angle and the deflection caused by the first flapwise bending mode. Analysis indicates that control schemes using sensors in the rotating system can utilize higher gains than can controllers using measurements from the non-rotating system. The higher gains permit more rapid control response and improved system effectiveness.

(S. Jacklin and J. Leyland, Ext. 6668)

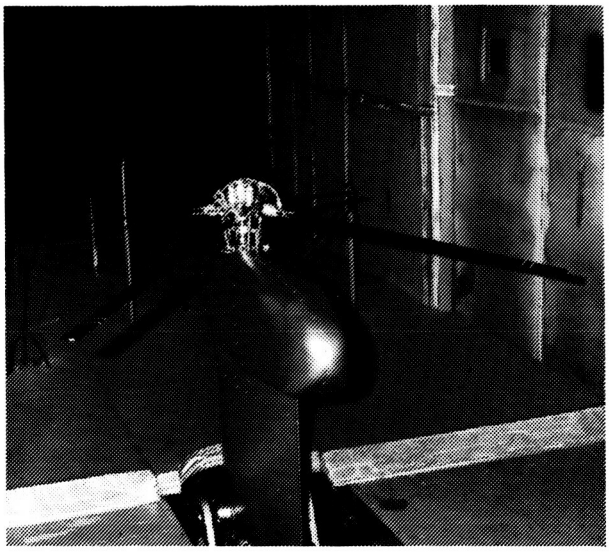


Rotor test rig with 1/6.31-scale S-76 rotor system

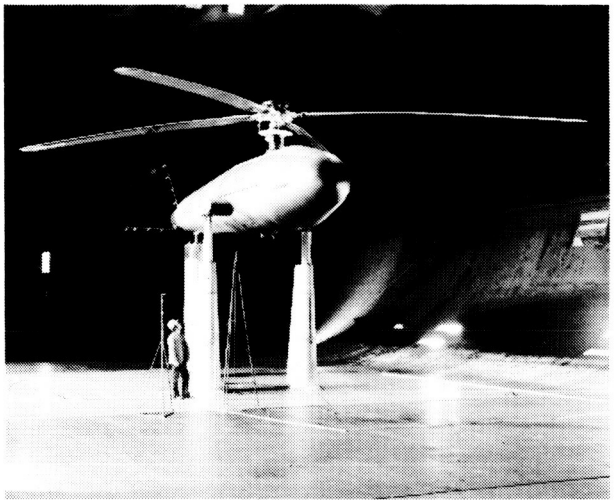
Facility Effects on Rotor Noise

Helicopter-model rotor testing necessitates the development of accurate methods to extrapolate small-scale results to full scale. The objectives of this program are to define the scaling effects and also the effects of the facility in which the test is performed; to develop methods to extrapolate the small-scale data to full scale; and to contribute to a data base for correlation with prediction methods. The experimental, helicopter-noise research program at Ames Research Center utilizes both small-scale and full-scale rotor systems.

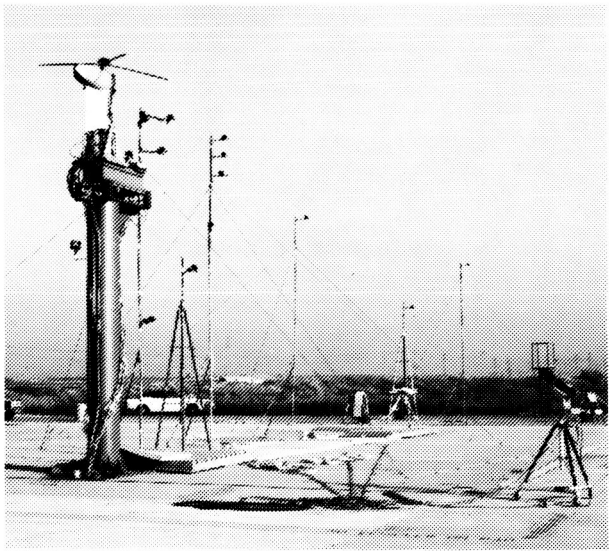
Several tests performed as part of this program are shown in the accompanying figure. The rotor systems used were a full-scale rotor and 1/6-scale



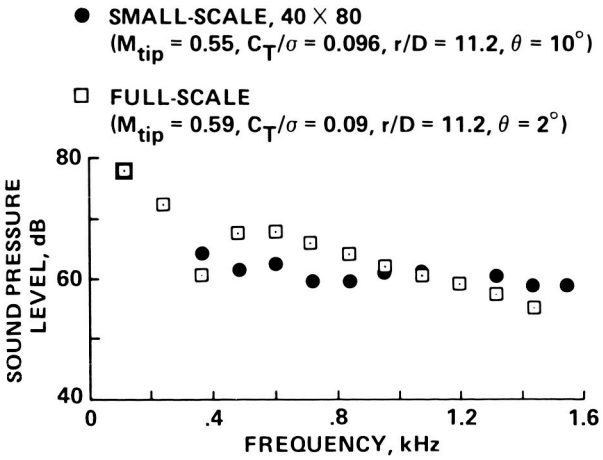
Small-scale test rig in 7- by 10-Foot Wind Tunnel



Full-scale test rig in 40- by 80-Foot Wind Tunnel



Small-scale test rig at OARF



Comparison of small-scale and full-scale rotor acoustic harmonics in hover

Effect of model scale and facility on rotor noise

model of a four-bladed, modern, civil helicopter, shown in the center of the figure. Hover tests of the small-scale rotor have been performed at the Ames Outdoor Aerodynamic Research Facility and in the test section of the 40- by 80-Foot Wind Tunnel. The results of these tests show that the operating environment and detailed test configuration have a major impact on the acquired data. Some comparisons were made with FAA flight-test data (see figure). A small-scale, forward-flight test was performed in the 7- by 10-Foot Wind Tunnel and the data were compared to data acquired in a previous full-scale 40- by 80-Foot Wind Tunnel test. This latter test was conducted in a reverberant environment.

Over the next several years, additional tests will be carried out with both small-scale and full-scale models in the 40- by 80- and the 80- by 120-Foot Wind Tunnels. These tests will provide the opportunity of evaluating the advantages of testing small models in large facilities as opposed to full-scale models, as well as add to the data base for further correlations.

(C. Kitaplioglu, Ext. 6679)

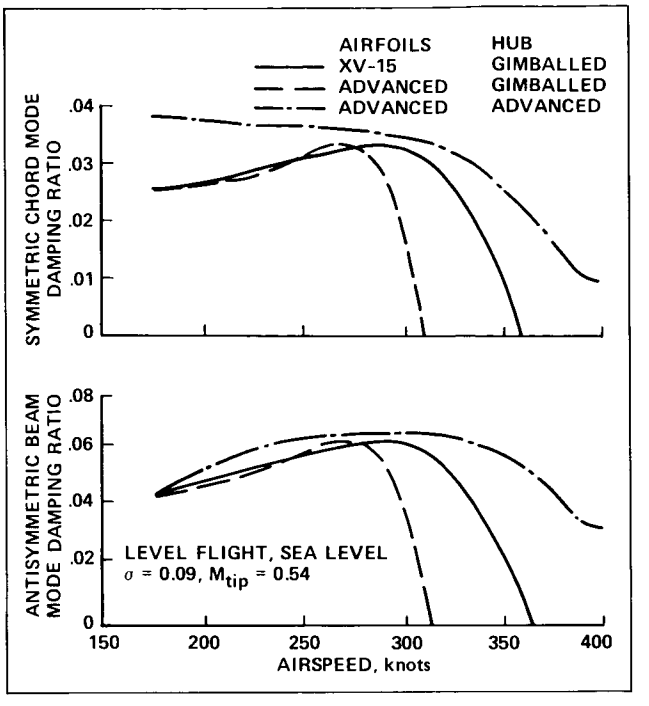
High-Speed Tilt-Rotor Aircraft

Over the past years, the successful test-flight program of the XV-15 Tilt Rotor Research Aircraft has validated the prop rotor concept. Tilt-rotor aircraft combine vertical takeoff and landing capabilities with high-speed and cruise flight. In this investigation, the feasibility of operating a faster tilt-rotor aircraft was examined. Designs with cruise speeds in excess of 400 knots were investigated.

In the study of high-speed, tilt-rotor designs, the comprehensive rotorcraft analysis program CAMRAD was used to calculate the aircraft's performance, whirl-flutter stability, and maneuverability. A preliminary design code was used to examine the sensitivity of aircraft weight to various design parameters. At a design speed of 400 knots, two representative aircraft were considered: a 46-passenger civil transport and an air-combat/escort fighter.

At high speed, the coupled motion of the wing and rotor on a tilt-rotor aircraft can become unstable. This instability problem is more severe when advanced airfoils are used on the rotor. However, this instability can be eliminated by introducing an advanced rotor hub configuration. To reflect current technology, advanced wing airfoil and airframe structural weights were also considered in the analysis. This preliminary study concludes that such tilt-rotor aircraft are practical, and identifies future directions for developing technologies for high-speed tilt rotors.

(B. Lau, Ext. 6653)

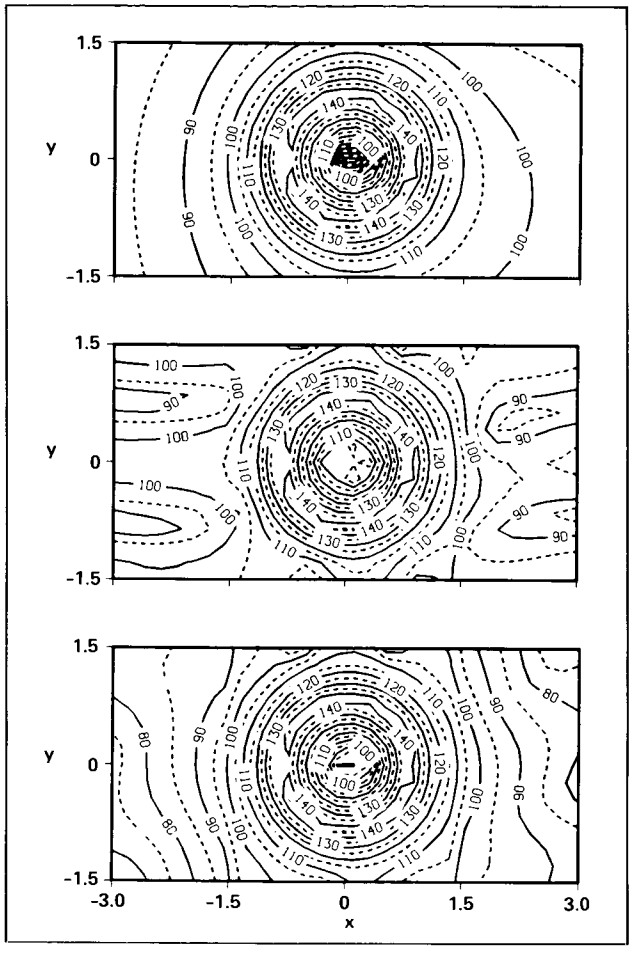


Calculated influence of advanced airfoils and hub configuration on tilt-rotor stability

Influence of Wind Tunnel Walls on Rotor Harmonic Noise

Accurate estimation of sound levels from a new helicopter design is needed early in a helicopter's development. Measuring noise in a closed-test-section wind tunnel provides one method to estimate the sound levels. However, the wind tunnel flow environment, background noise, and reflections of sound off wind tunnel walls modify sound levels measured in a wind tunnel. The walls produce a complicated, semireverberant sound field in which it is difficult to extract the noise which is due only to the rotor.

A method has been developed that can be used to examine the effects of wind tunnel walls on discrete frequency noise, such as the rotational noise produced by a helicopter rotor. The current



Sound contours of a helicopter in a wind tunnel

model consists of an arbitrary, known, harmonic-acoustic source of finite dimension inside an infinite duct of constant cross-sectional area with a uniform, subsonic flow. This model assumes sound propagates linearly in the duct. An impedance boundary condition on the duct wall allows the wall to absorb some of the incident acoustic energy.

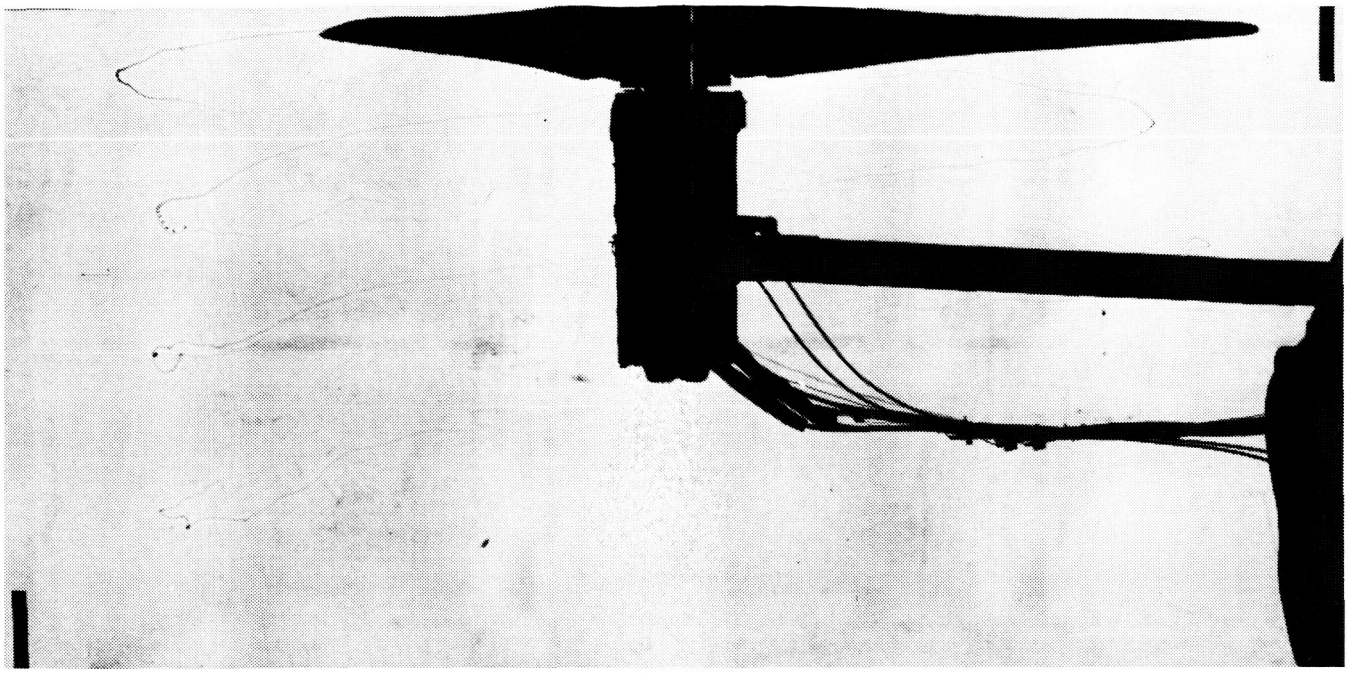
Calculations were made of low-frequency rotation noise for a helicopter model, both in unbounded space and in a rectangular duct with various sound-absorbing properties. Examples shown in the figure are contours of the constant pressure across a planform of the duct. The rotor hub is located approximately at the center of the duct. Close to the rotor, the sound field inside the duct resembles the free field, shown in the top figure for comparison. In a hard-walled duct and in a duct with small, but realistic, levels of sound absorption (middle figure) this region extends about one-half duct width (one rotor diameter in this example) from the rotor hub, except close to the duct walls. Outside this region, the reverberant sound field dominates and can significantly distort the sound pattern. These results are very sensitive to such duct parameters as size and wall absorption. Higher absorption (shown in the bottom figure) extends the useful region. Since sound absorption of acoustic liners increases with frequency as the source frequency increases, the useful region expands in an acoustically lined duct.

(M. Mosher, Ext. 6719)

Visualization of Rotor Wakes Using the Shadowgraph Technique

As part of a continuing study of rotorcraft flow fields, an investigation was undertaken to demonstrate the ability of the wide-field shadowgraph technique to provide tip-vortex geometry measurements for hovering rotor systems. This was accomplished by acquiring shadowgraphs over a wide range of operating conditions for three model main-rotor systems: a 0.16-scale model of the Sikorsky S-76, a Model 360 rotor system (tested in the Deutsch-Niederlandischer Windkanal), and a generic, highly twisted tilt-rotor model. From these shadowgraphs, axial and radial tip-vortex coordinates were measured. A second objective of this investigation was to show how the shadowgraph wake-geometry measurements could be used to help validate a hover-performance prediction code. This was accomplished by estimating certain wake-geometry parameters from experimentally determined tip-vortex coordinates. These parameters were then input into a lifting-surface hover code to predict the rotor performance. These predictions were compared in order to measure rotor performance to assess the validity of the prediction code. The final objective of the investigation was to develop a method to predict the visibility of a rotor's tip vortex on a shadowgraph. This was accomplished by using a combination of analytical and empirical results to help estimate a visibility function. This function was then used in conjunction with experimental data to quantify the ability of the shadowgraph technique to visualize a given number of tip vortices in the rotor wake.

In addition to the above investigation, Ames Research Center (ARC) has recently acquired wide-field shadowgraphs of the wake of a full-scale tail rotor tested at its Outdoor Aerodynamic



Shadowgraph visualization of the wake of a hovering model tilt rotor

Research Facility. Wake-geometry data acquired from this investigation will be compared with similar data to be acquired during a later 40- by 80-Foot Wind Tunnel test. This comparison will help determine the effect of the wind tunnel walls on the rotor wake geometry.

In conjunction with the ARC efforts, the Jet Propulsion Laboratory is continuing its work to develop a computer-software system that will extract three-dimensional (3-D) vortex trajectories from a pair of shadowgraphs. This work consists of three phases. The first phase, already completed, included the development of the techniques and software to digitize and enhance two-dimensional (2-D) vortex shadowgraph images. The second phase includes the development of the techniques (such as use of an x-y tablet) and software to determine 3-D vortex curve geometries from two digitized, synthetic 2-D images. The final phase will include the application of the system to analyzing shadowgraphs of helicopter rotors.

(T. Norman and J. Light, Ext. 6096)

Aeroelastic Stability Program

Current-generation helicopter rotor systems are sophisticated mechanical systems which operate with very high loads in an adverse aerodynamic environment. To relieve the high rotor-blade root moments and maintain dynamic stability, helicopter rotor blades typically have several hinges, bearings, and/or dampers at the blade root. These mechanical devices operate in the rotating system and experience large oscillatory loads. They require frequent maintenance and can drastically reduce the reliability of the rotor system. With the recent development of composite materials that can withstand higher loads, advanced rotor systems have been designed with a minimum of hinges and bearings. These systems have reduced the maintenance and improve reliability without degrading the aerodynamic performance or stability.

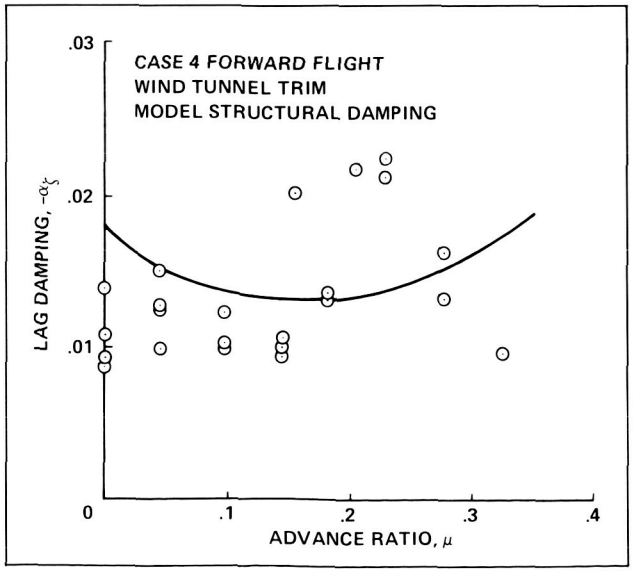
Previous full-scale wind tunnel test programs, as well as some flight tests, have verified the feasibility of such designs and the structural and operational integrity of the rotor systems. However, several very important areas of hingeless and bearingless rotor technology have not been adequately investigated. For example, the dynamic and aerodynamic characteristics of these rotors in forward flight have not been fully determined. Two test programs will further investigate the aeroelastic

stability of hingeless and bearingless rotors. In one, a BO-105 hingeless rotor system will be used. For the other, a new, advanced, bearingless rotor system is being designed and built by Boeing-Vertol.

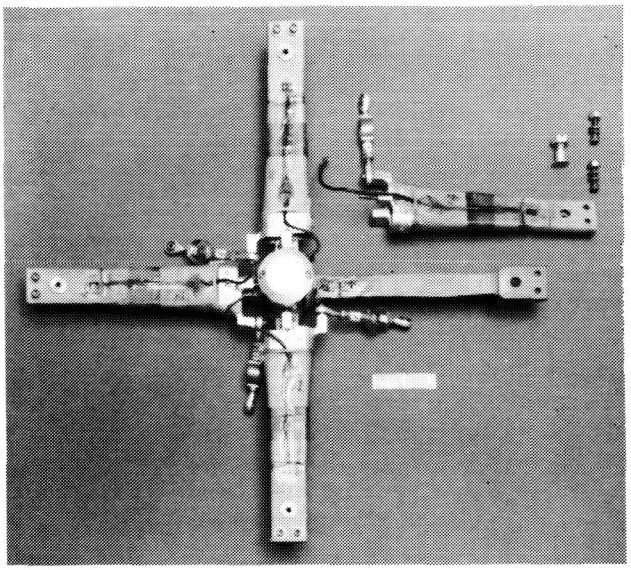
Concurrently, two analytical studies are being conducted on bearingless rotors in both hover and forward flight. One study (being conducted by Syracuse University) involves the extension of the transfer matrix approach to multiple-load-path rotor blades without resorting to an equivalent single-load-path approximation. This method has compared well with existing finite-element techniques in hover. Future plans involve the extension of this method to study the aeroelastic stability of bearingless rotors in forward flight.

The other analytical study is being conducted by the University of Maryland. This study utilizes a finite-element formulation to investigate the aeroelastic stability of bearingless rotors in forward flight. This analysis was used in a correlation study of the Boeing Vertol integrated technology rotor (ITR) model in both hover and forward flight. Hover stability calculations showed excellent correlation with the experimental data. The forward-flight stability calculations with wind tunnel trim and measured model structural damping showed good correlation with the experimental data as shown in the figure. Also shown is the ITR model hardware.

(R. Peterson and T. Graham, Ext. 5044)



Lag mode stability for Case 4, wind tunnel trim, 1.5% structural damping



Small scale advanced bearingless rotor system hub hardware

Aerodynamic Interaction Program

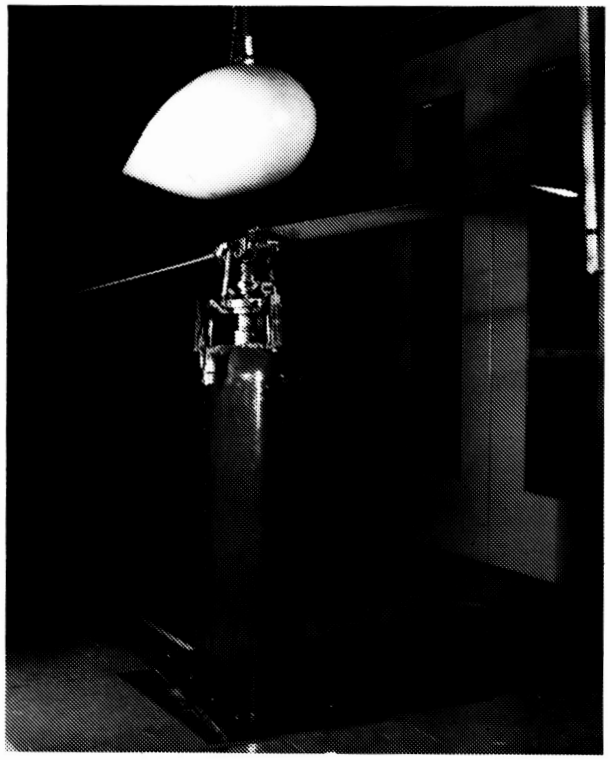
The flow field around any single helicopter component, such as the main rotor or the fuselage, is extremely complex. When isolated aerodynamically, each component has its own unique flow field and resultant aerodynamic characteristics. Present analytical techniques can predict reasonably well the flow around such isolated components. However, when in close proximity to one another, as in the helicopter, each component encounters an unsteady, nonuniform flow induced by all the other components. Hence, the total flow field is influenced not only by the flow around each component, but also by the mutual interactions between the components. These interactions produce increased steady and unsteady loads, increased vibration, and high noise levels.

Several experimental and theoretical investigations have been conducted (and more are planned) to provide detailed quantitative information on the aerodynamic and acoustic interactions that occur between various helicopter components. Two small-scale, experimental investigations and one theoretical study of rotor/body interaction have been completed. Future tests include small-scale studies of rotor/body interaction with a modern four-bladed rotor system in which flow visualization will be used to clarify the interaction process, and full-scale studies of

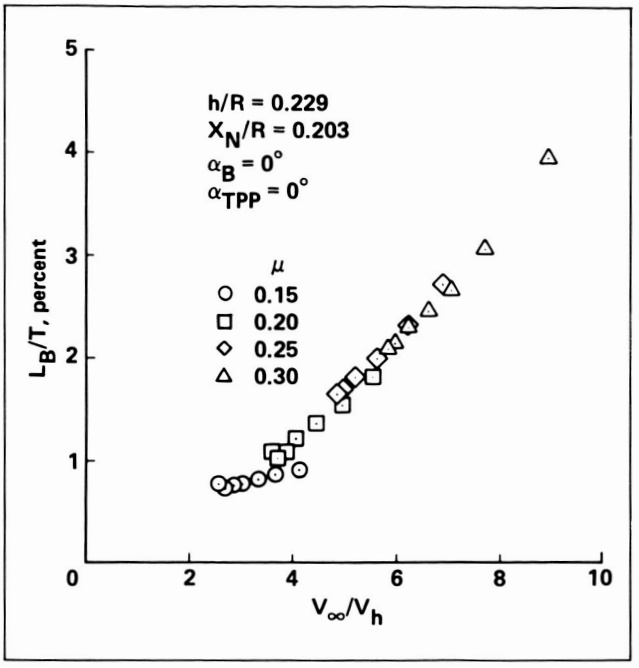
rotor/fuselage and main rotor/fuselage/tail rotor interaction. Additional theoretical work in these areas is also planned.

The figure depicts some of these tests as well as some results from the past experimental and theoretical investigations. The experimental results indicate that body loads, normalized by rotor thrust, scale proportionally to a velocity ratio based on the free-stream velocity and the induced velocity of the rotor wake. Calculated oscillatory blade bending moments were always increased by the presence of the body for the cases considered thus far.

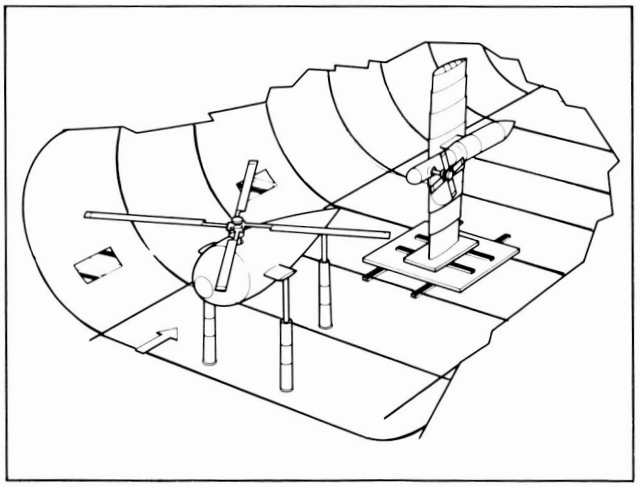
(P. Shinoda and C. Smith, Ext. 6679/4055)



a) Small-scale rotor/body test

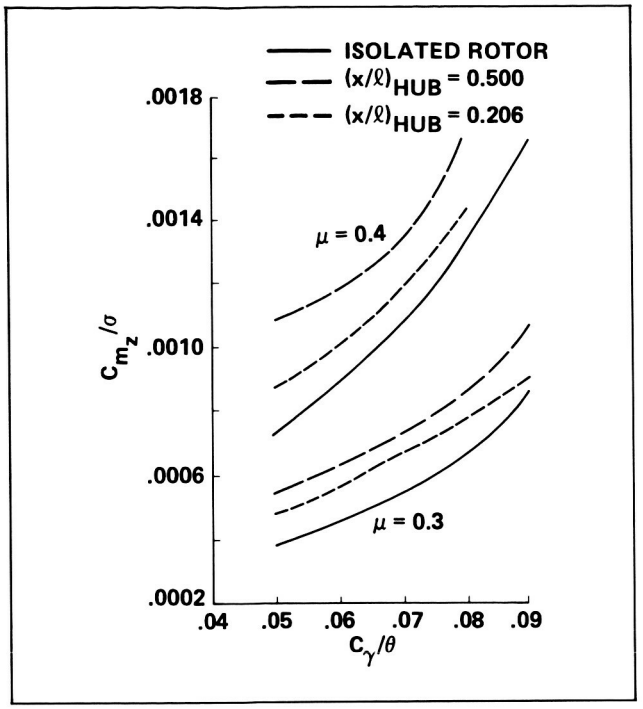


b) Body lift vs. velocity ratio



c) Aerodynamic interaction study — main rotor/body/tail rotor

Aerodynamic Interaction Program



d) Effect of hub position on the oscillatory edgewise bending moments at 0.5 R for two advance ratios

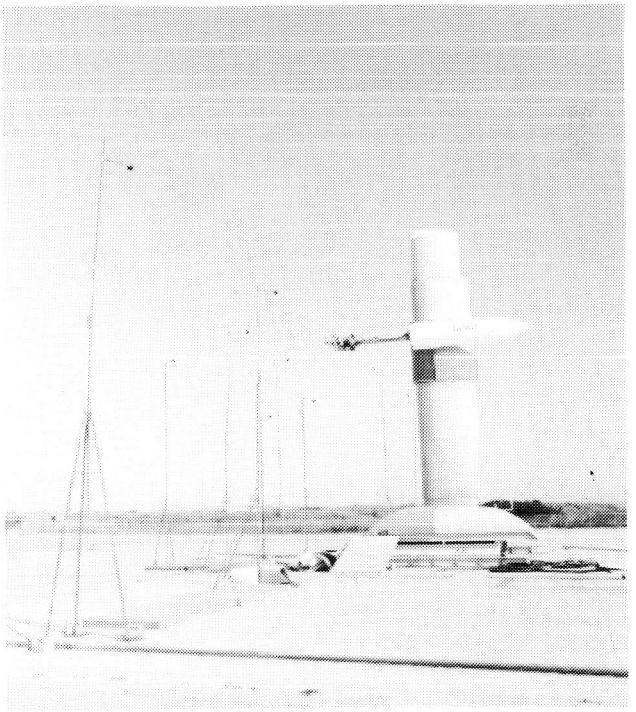
Tail-Rotor Noise Mechanisms

The tail rotor of single main-rotor helicopters can be the predominant noise source. This is primarily because the tail rotor operates in the complex flow field of the main rotor and fuselage wakes (which are themselves not well understood). The principal sources of this complex flow are the overall main-rotor downwash field, main rotor-tip vortices, separated flow from the fuselage, and turbulence in the main rotor and fuselage wakes. The noise caused by the interaction of the tail rotor with this flow environment is difficult to predict, and often is just as difficult to measure. For example, when making outdoor hover noise measurements of a rotor, the interaction noise caused by the atmospheric turbulence has been found to be an additional noise source that should be included when correlating with analytical predictions.

A program has been initiated to investigate the more important of these contributions to the complex flow around a tail rotor. The experimental portion of the program will utilize a full-scale tail rotor mounted on a three-dimensional traversing system. This test rig includes a balance system to measure tail-rotor performance. The first test, shown in the figure, is a hover test in which the contribution of atmospheric turbulence to the rotor broad-band noise will be measured. Both the near-field and the far-field turbulence will be measured and correlated with noise measurements. In addition, comparison of the turbulence at the two locations will permit a determination of the distortion of the atmospheric turbulence as it flows through the rotor. This will aid in the development of improved inflow models for use in correlating with hover measurements acquired outdoors. Subsequent testing will investigate the effect of the main rotor and fuselage on the noise generated by the tail rotor in forward flight.

A theoretical investigation will develop improved aeroacoustic models and will compare predictions to existing data. Previous research has shown that accurate models of both the inflow to the tail rotor and of the tail-rotor noise mechanisms are necessary for accurate predictions. Thus, work will be done on developing sufficiently accurate combinations of aerodynamic and acoustic models to be able to understand and predict the various noise mechanisms of tail rotors.

(D. Signor, Ext. 5044)

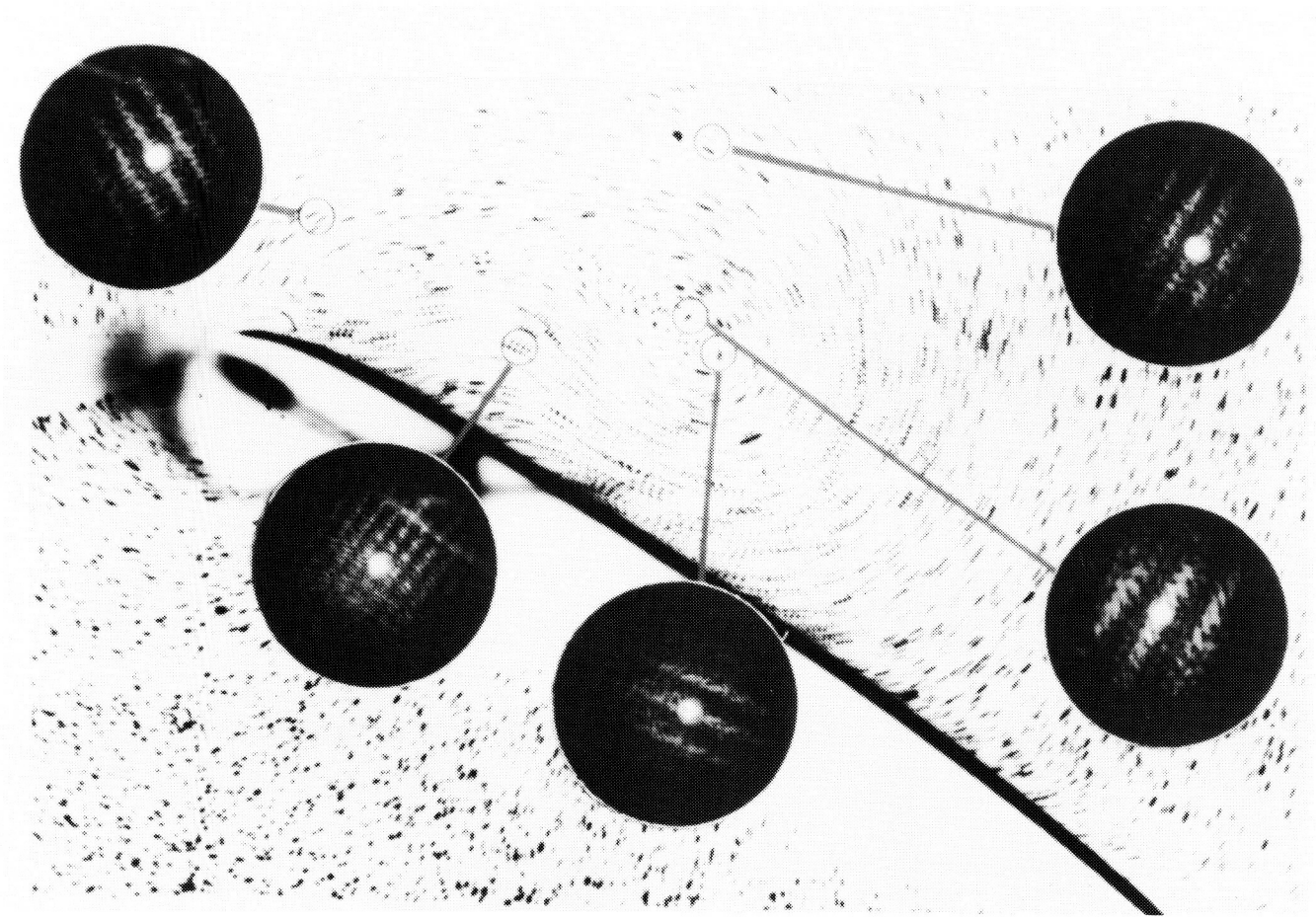


Acoustic measurements near an isolated tail rotor

Laser Speckle Velocimetry

Two of the most important and challenging problems in experimental fluid mechanics are the measurement of the velocity field and the measurement of the vorticity field. Local measurements of the velocity field (i.e., at individual points) are now done routinely in many experiments. However, most of the flow fields of interest (such as rotor flows) are highly unsteady. Laser velocimeter (LV) data of such flows are difficult to interpret as both spatial and temporal information of the entire flow field are required, and these methods are commonly limited to simultaneous measurements at only a few spatial locations. Although the vorticity field is an essential property of most flows, measurements of this quantity exceed present experimental capability. This difficulty arises from the fact that vorticity is a quantity defined in terms of local velocity gradients. In contrast, the currently available measurement techniques are sensitive only to the local velocity. Thus, measurements must be made over several points and the resulting velocity components are then analyzed by finite difference schemes. Recently, a novel flow-velocity measurement technique, commonly known as Laser Speckle Velocimetry (LSV), has been developed. This technique provides the visualization of the two-dimensional (2-D) streamline pattern in an unsteady flow as well as the quantification of the instantaneous velocity field. The principal advantage of this new technique is that the 2-D velocity field over an entire plane can be recorded in a single measurement, with great accuracy and spatial resolution. From this measurement the instantaneous vorticity field can be easily and directly obtained.

The experimental setup itself is quite simple. A plane of interest in the fluid, seeded with microparticles as scatterers, is illuminated by a coherent light source (usually a pulsed laser). This plane is then imaged through a lens onto a photographic film or plate, and a double-exposed photograph is taken. Through the appropriate choice of the time interval between exposures, information on



Flow past wing at high angle of attack

the local particle velocities is stored on the photograph and may be transformed to a fluid-flow pattern through microscopic inspection. Recent advances in the field of digital image-processing provide a quick method for the derivation of the velocity and vorticity fields. In the first step, image displacement is derived by illuminating a small portion of the photographic transparency with an unexpanded laser beam. The diffraction produced by coherent illumination of the multiple images in the negative generates a pattern similar to Young's fringes in the Fourier plane of a lens. These fringes have an orientation perpendicular to the direction of the local displacement and a spacing inversely proportional to the displacement. Results for the flow past a circular cylinder are shown in the figure. Most of the work in this field has been developmental in nature and has involved studies at very low speeds, usually in liquid. Future plans for this program are to utilize an extremely high-powered pulsed laser for the first use of LSV in a wind tunnel study. The flow field over an airfoil at high angle of attack will be measured at speeds up to 70 m/sec and Reynolds numbers up to one million.

(C. Smith, Ext. 4055)

Numerical Methods for Vortical Flow Fields

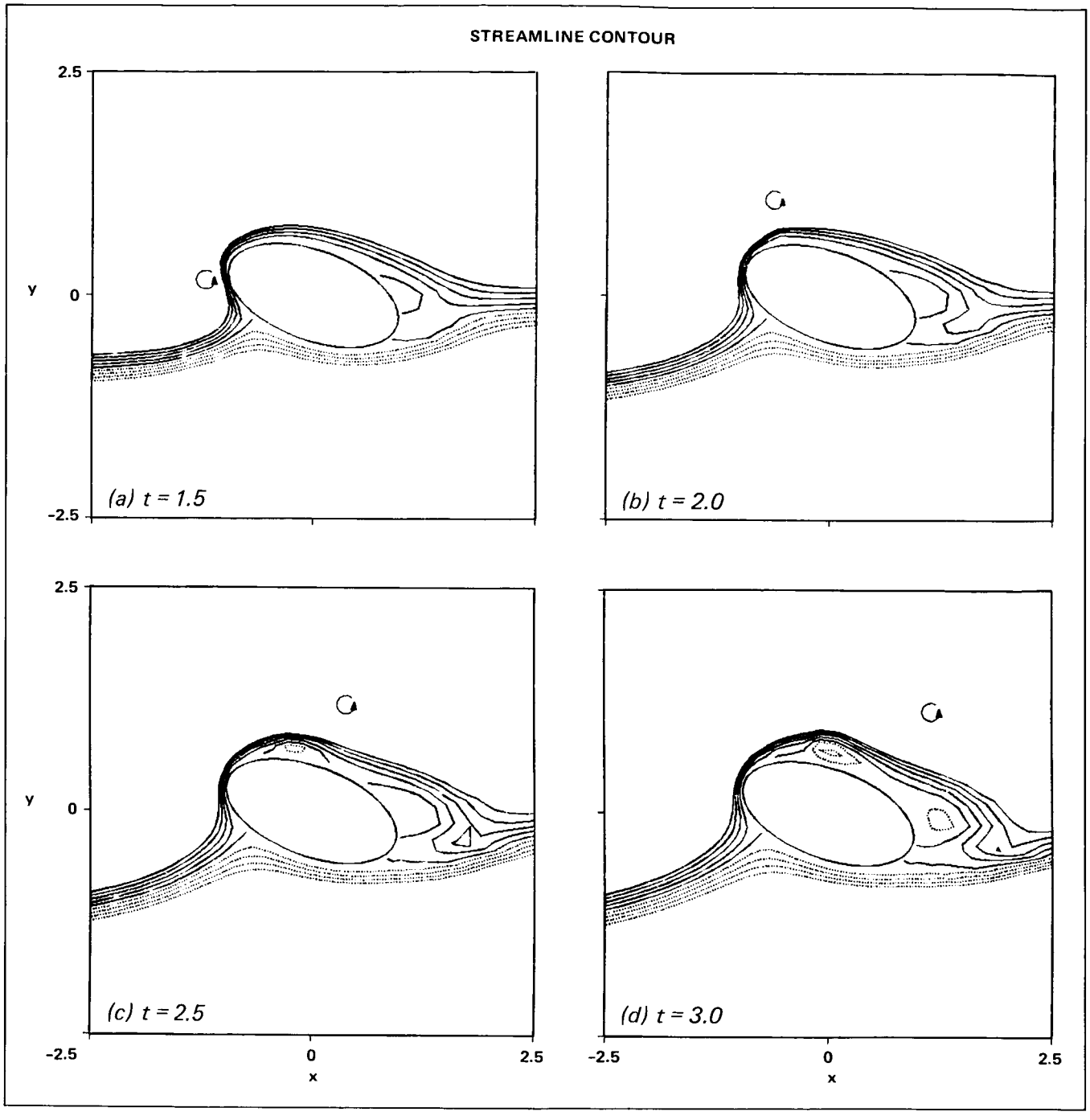
During hover and low-speed flight, several important interactions occur between the vortex wake shed from the rotor blades and the other helicopter components. For example, there is the direct impact of the rotor wake on the forward section of the fuselage, the tail boom, and the empennage surface. The prediction of this strong interaction between vortical wakes and the viscous flow field about bodies is of considerable importance in the design and analysis of rotorcraft. Payload predictions, vibratory loads in the cockpit, and loads on the tail boom are all dependent on an understanding of vortex wake/surface interactions.

The three-dimensional (3-D) flow field beneath the rotor disk and the interaction of the rotor wake with surfaces in the flow field are highly complex and difficult to model. To provide a basis for understanding these interactions, a simpler problem has been addressed first: the two-dimensional (2-D) interaction of an external vortex wake with the viscous flow about an arbitrary body. A full understanding of this topic will assist in the solution to the full 3-D flow field.

This method solves for the flow-field velocities on a body-fitted computational mesh using finite-difference techniques. The flow field is not constrained to steady or symmetric flow. The external vortical wake is represented by an array of discrete vortices, which in turn are represented by a finite-core model. The evolution of the external vortical wake is calculated by Lagrangian techniques. The viscous flow field about the body is calculated on the body-fitted computational mesh via the vorticity transport equation. The influence of the external vortical wake is represented directly through the governing equations for the viscous flow field.

Results for the time-dependent viscous flow about arbitrary 2-D bodies in the absence of external vortical wakes have been calculated for Reynolds numbers up to 550. Specifically, the calculated drag coefficient, separated wake length, and point of flow separation for the flow about a circular cylinder are in good agreement with other numerical calculations and experimental results. The interaction of external vortical wakes with the flow about a circular cylinder has been calculated. This configuration modeled the interaction of a vortex wake shed from a rotor blade and the tail boom cross section beneath the rotor disk. The loading on the tail boom was found to be highly dependent on the location of the vortex wake shed from the rotor blade. The interaction of an external vortex wake with the flow about arbitrary 2-D bodies was also calculated. The interaction of external vortex wake modeled by a single finite-core vortex and the viscous flow about a 2:1 elliptic cylinder at 20° angle of attack was calculated. The figures show the streamline contours during the interaction between the external vortex wake and the viscous flow about the elliptic cylinder. The orientation and core radius of the external vortex wake are depicted on each figure. These results demonstrate the ability of the technique to model the interaction of vortex wakes with arbitrary bodies in 2-D. Future efforts will be directed toward extending the technique to 3-D.

(P. Stremel, Ext. 6714)



Streamline contours during vortex interaction

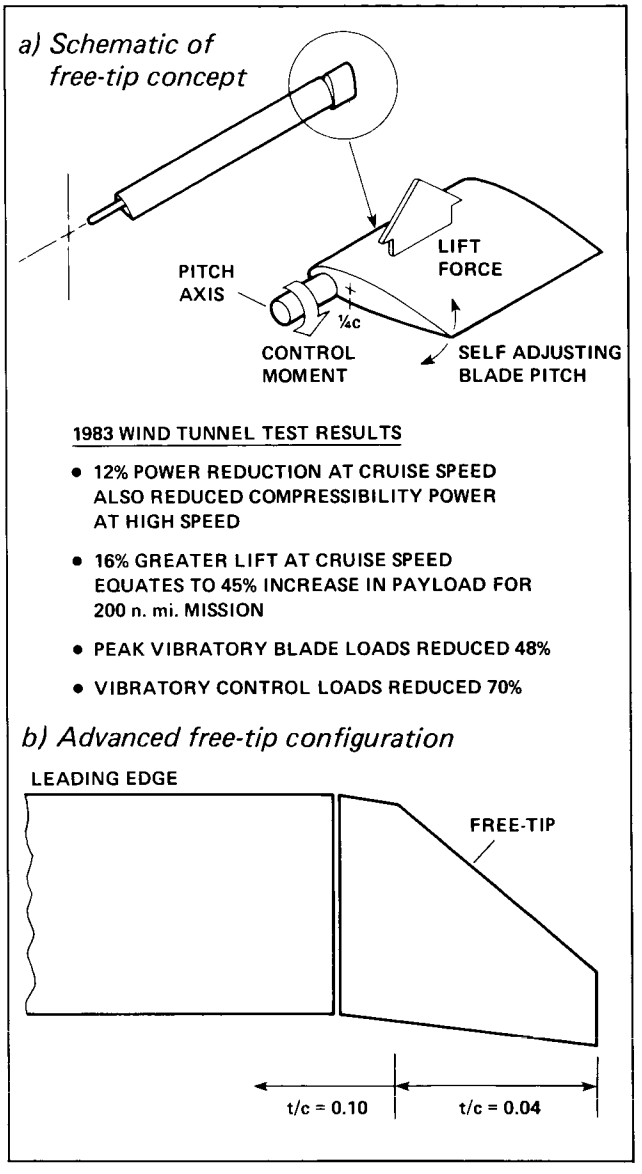
Free-Tip Rotor

Wind tunnel tests have shown the free tip to result in improved cruise performance and reduced oscillatory loads: power required was reduced by 12%, with an accompanying 40% reduction in maximum oscillatory blade loads and a 70% reduction in control system oscillatory loads.

The reason for the power reduction was demonstrated experimentally in a wind tunnel test of a semispan wing. In this test, a three-dimensional (3-D) laser Doppler anemometer measured the flow about the wing and the tip. These measurements showed a strong vortex shed from the junction of the tip and the wing, and an upwash over the tip when the tip was at negative incidence angle and the wing was lifting. This upwash over the tip caused the tip's lift vector to incline forward and substantially reduce the drag and consequently reduce the power. Thus, the power reduction produced by the free tip was related to the lift discontinuity between the tip and the inboard blade creating a vortex and inducing upwash over the tip. Recent studies have shown that an additional power improvement will result with a lower-drag airfoil for the tip. The free tip, which was only 10% of the blade span, produced a 40+% reduction in blade oscillatory flatwise bending. The large-percentage reduction in oscillatory airload resulted from the free tip sweeping a large percentage of the rotor disk sector having oscillatory airloads that produce vibration. This rotor disk sector is triangular in planform, with its apex at 90° azimuth station, and contains large airload fluctuations with 3-10/rev harmonic content. The 10% span free tip sweeps 57% of this sector and results in a high oscillatory load attenuation disproportionate to size of the tip. The free tip will be further investigated in a small-scale wind tunnel test in a joint NASA/Army program. The wind tunnel test will include investigation of performance, loads and acoustic, and will compare the free-tip to an advanced-technology, fixed-tip configuration. Hover testing will be included. Development of the small-scale model has begun, and the following actions have been taken:

1. VSAERO has been validated as a tip-planform design tool using semispan wing wind tunnel test data

2. A baseline free-tip planform has been defined using VSAERO



Free-tip rotor

3. Advanced free-tip configurations are being studied for inclusion in this test program. Of particular promise is a tip with its $t/c = 0.04$ for low noise and low compressibility power at high-tip Mach number

4. Tension-torsion straps have been selected as the means for tip retention and for applying the control moment. The straps have been built and have completed 70% of their performance and fatigue tests

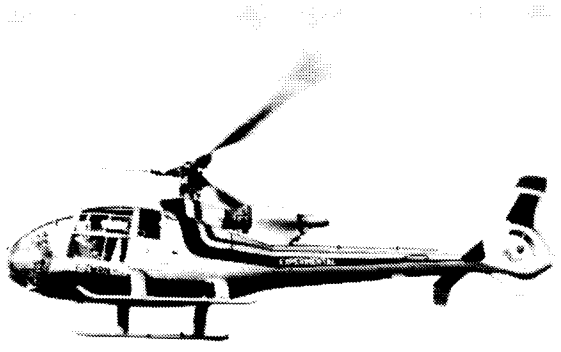
5. Design of the tip and the attachment to the inboard blade has been completed

(R. Stroub, Ext. 6732)

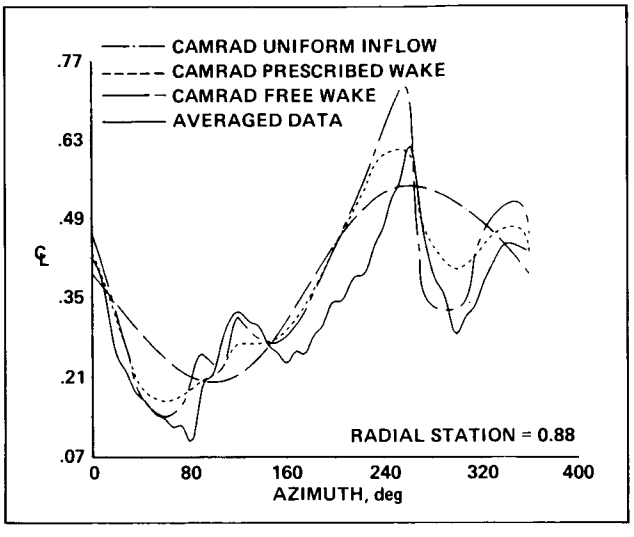
Correlation of SA 349/2 Helicopter Flight-Test Data with a Comprehensive Rotorcraft Model

A comprehensive rotorcraft model (CAMRAD) is being used to predict blade aerodynamic and structural loads for comparison with flight-test data. The data were obtained from an SA349/2 helicopter with an advanced-geometry rotor. These data include structural and aerodynamic loads, performance, and blade pressure measurements at several thrust levels and advance ratios. The analytical model – CAMRAD – can model a general two-rotor aircraft with either articulated, hingeless, gimballed, or teetering rotors. The rotor structural model is based on engineering-beam theory for rotating wings with large pitch and twist. The rotor aerodynamic model is based on lifting-line theory, and uses two-dimensional airfoil characteristics and a vortex wake. Three levels of modeling the inflow to the rotor exist in CAMRAD: uniform inflow, nonuniform inflow with a prescribed-wake geometry, and nonuniform inflow with a free-wake geometry. Sensitivity of the correlation to wake geometry, blade dynamics, and blade aerodynamic effects was investigated. Blade chordwise pressure coefficients were predicted for the blade transonic regimes using the CAMRAD model coupled with a full-potential, finite-difference aerodynamic code.

The figure shows blade section lift coefficient as a function of azimuth at a radial station of r/R = 0.88. For this flight condition (advance ratio = 0.14, thrust coefficient to solidity ratio = 0.065), uniform inflow is not able to predict the details of the lift variation. The prescribed wake results are better, but still do not predict the details of the variation with azimuth. The free-wake geometry, however, is able to predict both the trend and magnitude of the lift.



SA349/CAMRAD correlation study



Effect of wake geometry on lift prediction

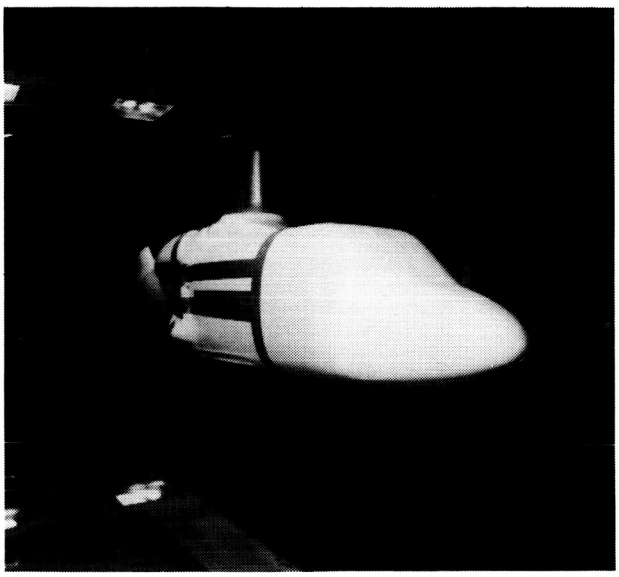
Other results for this flight condition show that nonuniform inflow is also required to predict blade structural loads. Although the free-wake model was not important in predicting flapwise moments, it was required for calculating edgewise bending moments.

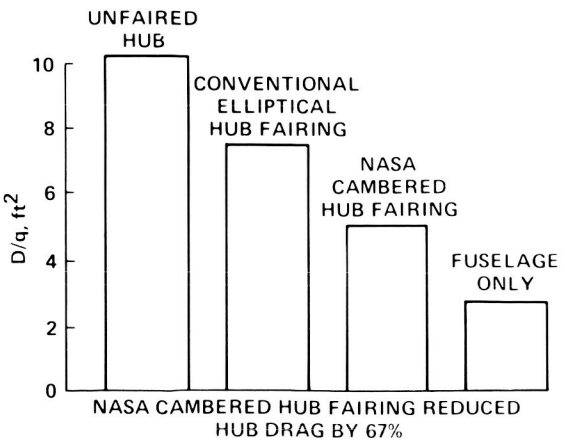
(G. Yamauchi and R. Heffernan, Ext. 6719/5043)

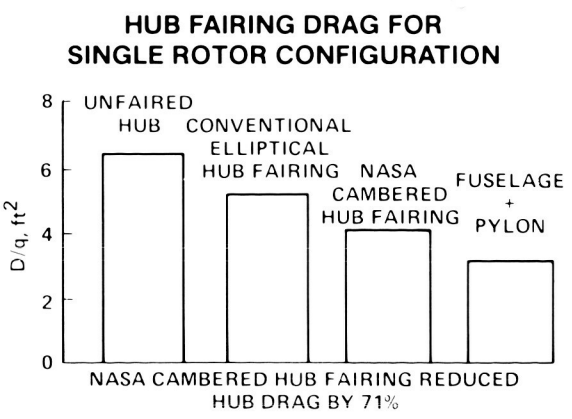
Hub-Drag Reduction

A wind tunnel test was conducted to obtain data on several rotorcraft hub and shaft fairing configurations. The objective of the test was to use small-scale, simplified test models to develop the technology to substantially reduce hub drag. Aerodynamic moments and loads, and flow-visualization photographs were acquired for the model configurations. Hub fairings for both coaxial- and single-rotor configurations were tested. All rotor assemblies were modeled with nonrotating hardware. Test data suggest that significant drag reductions can be attained. For single-rotor fairing configurations, a cambered, elliptical, hub fairing results in less drag than a comparable elliptical hub fairing, particularly when both are used in conjunction with a low-drag shaft fairing. It was also determined that single-rotor shaft-fairing geometry is important for reducing interference drag when used with a low-drag hub fairing. For coaxial-rotor fairings, a cambered elliptical fairing configuration with the hub fairings having flat lower surfaces had the lowest drag.

A second small-scale wind tunnel test is planned. This test will concentrate on four areas: including blade shanks into hub fairings; studying







Hub drag-reduction program

the effect of hub and shaft fairing spacing, and hub fairing height, on interference drag; studying alternative forms of the low-drag fairing configurations identified in the first test; and arriving at a better understanding of the hub and shaft fairing drag mechanisms. New hub fairings will be tested that encompass variations in fairing thickness ratio, camber, and surface curvature (including reflexed surfaces). New shaft fairing contours will include variations in maximum width location, afterbody shape, thickness ratio, and camber. A greater understanding of the hub and shaft fairing drag mechanisms will be acquired by more extensive flow visualization using both tuft and oil photographs.

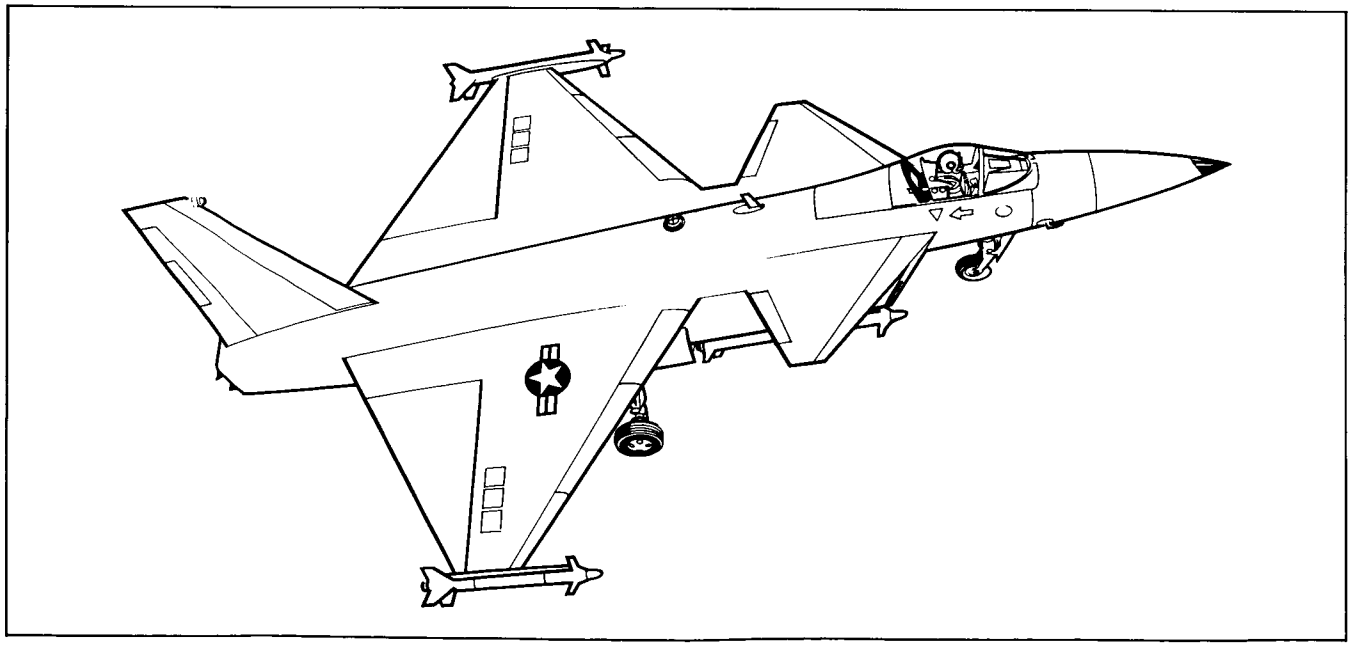
(L. Young and D. Graham, Ext. 6732/6976)

Supersonic STOVL Fighter Design Studies

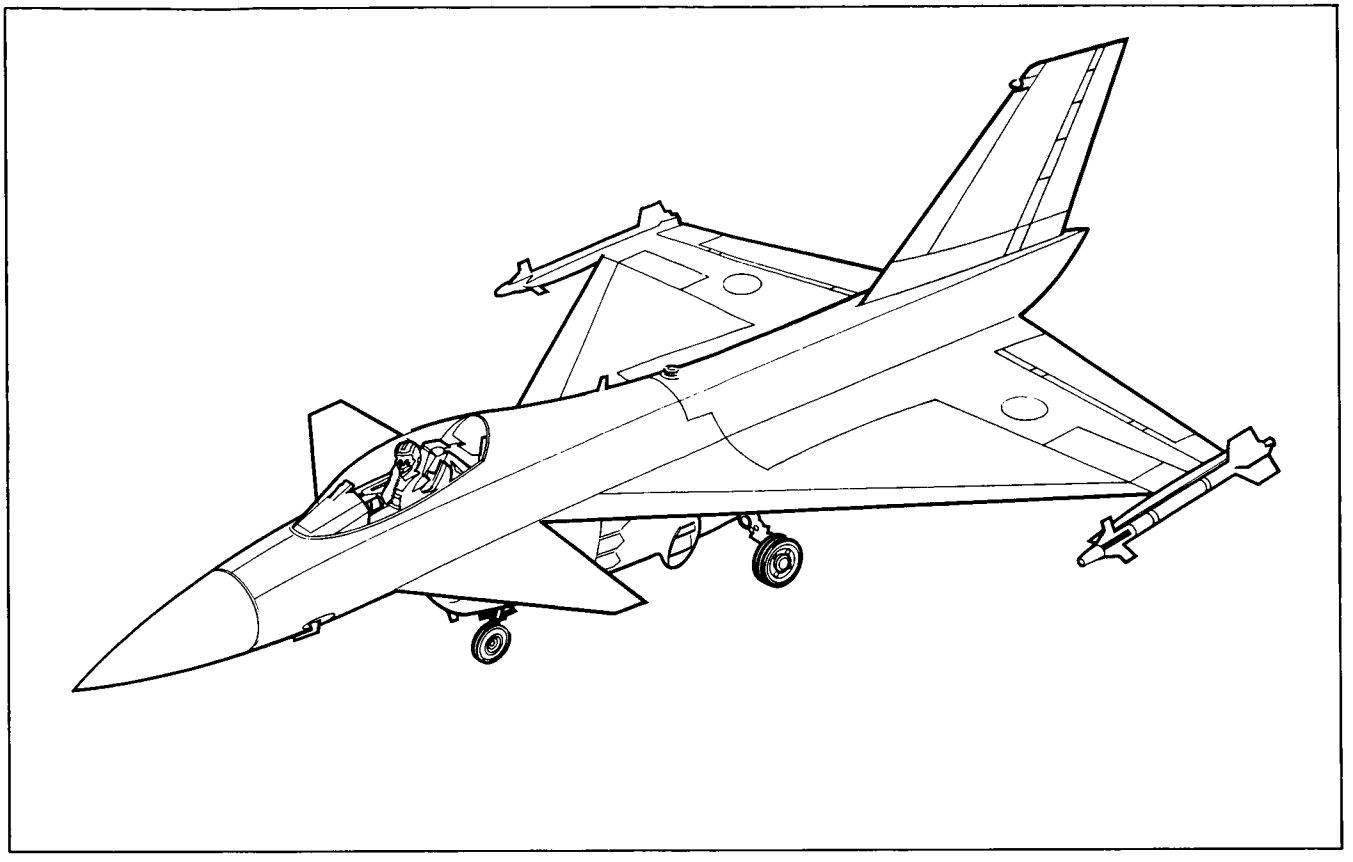
Conceptual design studies of single-engine, supersonic, STOVL fighter aircraft are being performed in-house by NASA in support of the U.S. and U.K. Advanced Short Takeoff and Vertical Landing (ASTOVL) program. The studies are a cooperative effort between three NASA Research Centers: Ames, Lewis, and Langley. Four ASTOVL propulsion system concepts — ejector-augmentor, remote augmented-lift system (RALS), vectored thrust, and tandem-fan — are being modeled, and aircraft configurations are being developed to evaluate the capabilities of these concepts. The studies are to: (1) formulate and evaluate the concept evaluation model (mission, performance, and payload) for the U.S./U.K. contracted studies; (2) further an in-house expertise in supersonic STOVL concepts so as to be in a position to effectively monitor and guide the four contracted studies; and (3) develop reports, guidelines, criteria, etc., for use in the normalization and down-selection process at the end of the contracted studies.

In order to use the capabilities of the three NASA Research Centers, an iterative process has been developed. Initial engine performance is estimated at Lewis with the NASA/Navy engine program. These propulsion data are used to develop an initial configuration at Ames using the aircraft synthesis program ACSYNT. Detailed weight and aerodynamic performance are then evaluated at Langley. The preferred engine cycles are identified and the design process is repeated. The figures show the latest iterations of the RALS and tandem-fan concepts.

(P. Gelhausen and P. Nelms, Ext. 6276/6093)



Supersonic STOVL fighter aircraft (RALS configuration)



Supersonic STOVL fighter aircraft (tandem fan configuration)

Study of a Propulsion System for a Supersonic STOVL Flight-Research Aircraft

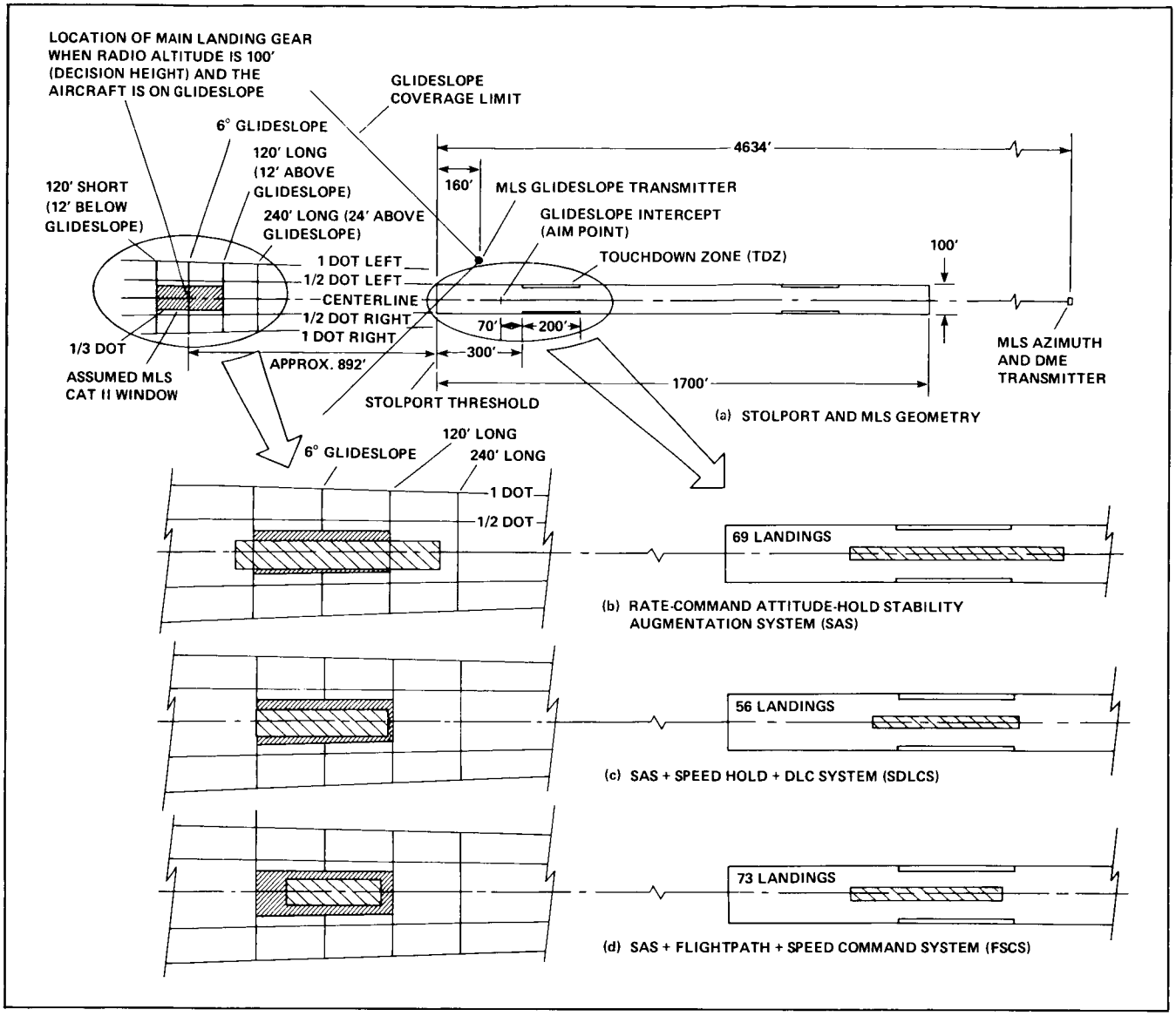
Pratt & Whitney of the United Technologies Corp. is under contract to Ames Research Center to evaluate a derivative of the PW5000 engine as a candidate propulsion system for a potential supersonic STOVL flight-research/proof-of-concept demonstrator aircraft. This ground-based research program is a cooperative effort with Defense Advanced Research Projects Agency (DARPA) and the Air Force. Four powered-lift propulsion systems are under consideration: vectored thrust, ejector augmentor, remote augmented-lift system, and hybrid tandem fan. The contracted effort includes three authorized tasks: (1) concept definition and trade-off studies, (2) reaction-control-system bleed tests, and (3) concept airframe integration, and two option tasks: (1) STOVL supporting engineering activities and (2) gas-generator preliminary and detail design. The first flight of a potential research aircraft could be in the 1992-1995 time frame demonstrating STOVL operation, supersonic capability, and supermaneuverability.

(D. Giuliannetti and P. Nelms, Ext. 5592)

Quiet Short-Haul Research Aircraft Flight Experiments

Flights experiments were conducted with Ames Research Center's Quiet Short-Haul Research Aircraft (QSRA) to evaluate the influence of highly augmented control modes on the ability of pilots to execute a precision approach to a 100-ft decision height (DH) and make a precision landing on a short runway.

The aircraft used is a powered-lift, short-takeoff and landing configuration that is equipped with a modern digital fly-by-wire flight-control system, a head-up display, and a color head-down display that make it possible to investigate control concepts and display format



Two-sigma tracking performance at 100-ft decision height and touchdown performance.

and content for full-envelope, powered-lift operations. Considerable attention has been devoted in this flight program to assessing flightpath and airspeed command and stabilization modes developed using nonlinear, inverse, model-following methods.

Flightpath-oriented display presentations that provide status and command information in a format with minimal clutter were also investigated. The pilot can fly the aircraft with the precision associated with flight-director guidance and with a high degree of situation awareness.

The benefits of these control and display concepts on the precision landing task are shown in the figure. The horizontal dispersion at the 100-ft, DH plane is shown on the left for three levels of control-system augmentation. All three used an advanced, electronic, head-down display. The data for the QSRA are shown by the crosshatched area referenced to the conventional aircraft CAT2 100 ft DH window. The touchdown performance is shown in the right of the figure. The crosshatched area shows the QSRS data. The runway geometry is shown in the top of the figure.

These concepts and their design criteria have been defined to the point that they are ready for applications in aircraft design when warranted by mission requirements or complex control configurations.

One practical application of this control and display work has been a consultation with the Air Force and McDonnell Douglas on the F-15 STOL maneuvering technology demonstrator program. The approach to a 50- by 1500-ft runway at 120 knots in a STOL F-15 has many similarities to our STOL and CTOL work.

(G. Hardy and D. Riddle, Ext. 5278/6085)

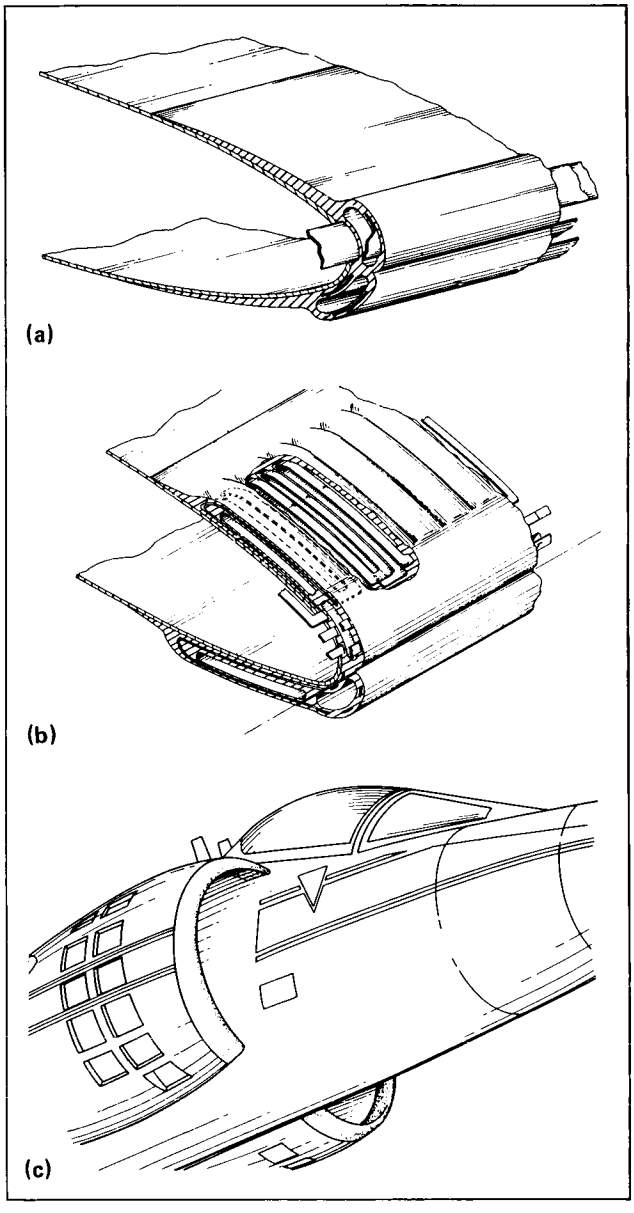
Electro-Expulsive Deicers for Rotorcraft and Fixed-Wing Aircraft

A major technological impediment to extending helicopter operations into the all-weather flight regime is the lack of rotor-blade ice protection. The sensitivity of the blades to ice accumulation is well recognized. Anticipated weight and power penalties for existing helicopters have been cited as a major reason users have been reluctant to incorporate ice protection on existing helicopters.

A low-cost, low-power, and lightweight solution to the problem of icing protection for helicopter rotor blades appears to be available from efforts of Ames Research Center personnel. The newly disclosed, next-generation deicing system has been described in a recent patent application. The electroexpulsive deicer boot is readily bondable onto almost any substrate, and requires no mechanical moving parts or pneumatic inflation to effectively shed ice from aircraft surfaces. The new deicer is an elastomeric boot that cyclically, expulsively expands and throws off any accreted ice.

The operation could be described as "snapping a small rug to shake the dust out." In the relaxed state, the thin deicer boot is flat against the airfoil surface with no significant voids in its interior. However, during fabrication of the low-temperature rubber boot, there are enclosed, unbonded sections included (resembling knife slits) which are completely surrounded by the elastomer. These slits are in between and in parallel with a series of high-voltage ribbon conductors embedded in the rubber.

When a bank of capacitors in the power supply is discharged into the conductors in a zoned-sequence pattern, the large pulse of electricity (about 3000 A discharged in less than a few milliseconds) suddenly induces these conductor pairs to repel one another with a powerful force. This force causes the slit-voids to expand vigorously (as in the rug-snapping simile) to throw



Electro-Expulsive Deicers for Rotorcraft and Fixed-Wing Aircraft. (a) Sectional perspective of a version of the electroexpulsive boot with the conductors electrified and portions of the elastomer vigorously distended to shed ice. (b) Perspective view of an overlapped serpentine ribbon conductor of the electroexpulsive deicing system, embedded in a flexible elastomer sheet. (c) View of deicing system retrofitted onto an engine inlet as a typical application

off any ice buildup. The voids immediately collapse again owing to the elastic rebound of the boot material, and thus the operation cycle has virtually no adverse effect on aerodynamic performance because of the rapidity of its action.

Although originally focused toward helicopter use, the Navy is the first to recognize this concept's utility for high-performance aircraft. An accelerated Navy/NASA program is under way to flight-test the electroexpulsive deicer on the F/A-18 Hornet.

(L. Haslim, Ext. 6575)

Light-Weight Telescoping Rescue Boom for Helicopters

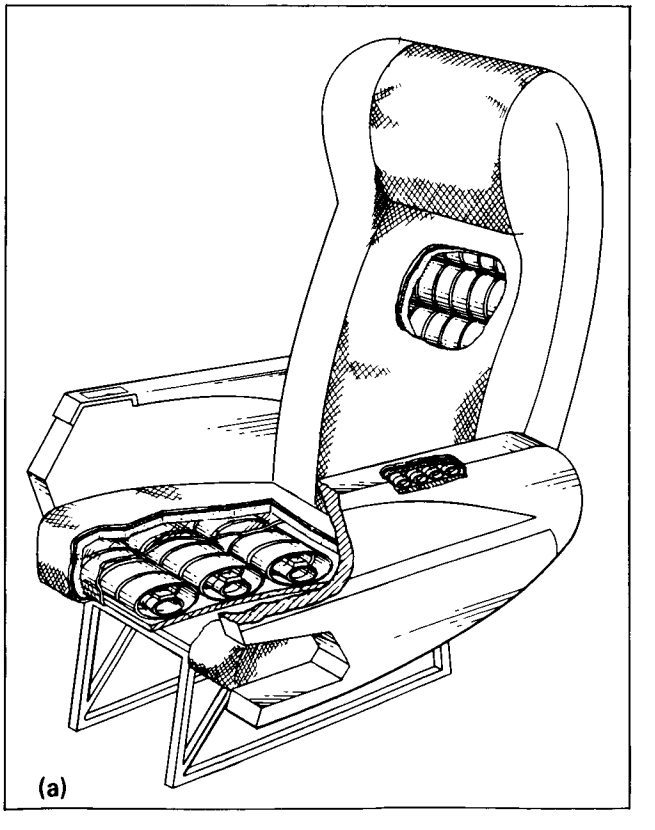
The HH-65A Dolphin helicopter entering the Coast Guard inventory does not have the capability of landing in water that its predecessors had. This shortcoming frequently requires crew members to jump into the open sea to effect a rescue, thereby increasing the overall risk. To improve the effectiveness and utility of their search and rescue helicopters, a Memorandum of Agreement has been signed between NASA and the Coast Guard to foster the development of an Ames Research Center concept for a light-weight, telescoping rescue boom for these helicopters. Modern composite technology is used to achieve the desired properties. The retractable boom is designed to project the existing rescue hoist cable end out front, within the pilot's vision and beyond the main rotor's downwash. Upon engagement, the cable falls free from the extendable boom and is wenched up in the conventional manner. The use of this device is expected to greatly improve the rescue capabilities of rescue helicopters confronting situations such as rough seas, mountainous terrain, and even high-rise building fires.

(L. Haslim, Ext. 6575)

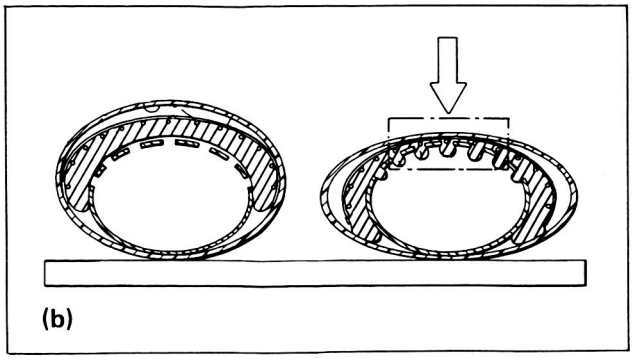
Light-Weight Fire-Retardant Crashworthy Aircraft Seat Cushioning

A novel, light-weight, energy-absorbing aircraft seat cushioning material with significantly improved fire-resistant properties has been invented. The design is to provide comfortable seating that meets aircraft-loading requirements without using polyurethane foam materials, which are highly toxic when ignited. The seat-design concept is shown in the figure, and consists of central, elliptical, string supports made of graphite-epoxy and surrounded by a fire-resistant polyimide belt. Crashworthy characteristics are imparted to the cushioning by incorporating a layer of energy-absorbing visco-elastic layers between the nested, elliptical strings. Aside from its fire-resistant and energy-absorbing characteristics, the seat cushion design is lightweight, simple to fabricate and maintain, and structurally strong.

(L. Haslim, Ext. 6575)



Light-weight fire resistant crashworthy aircraft seat incorporating novel spring system



Energy absorbing elliptical composite cushion spring system with visco-elastic innerliner to impart crashworthy property

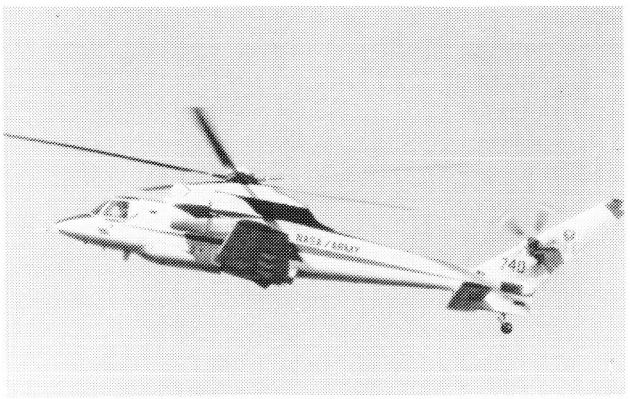
Rotor Systems Research Aircraft Flight Experiments Program

The Rotor Systems Research Aircraft (RSRA) was flown in 1986 in support of the X-Wing/RSRA program, Rotor Force Derivatives/ Parameter Identification program, and the S-61 Performance program. The flights were flown to provide NASA and Sikorsky X-Wing/RSRA project pilots training and experience in flying the RSRA prior to the X-Wing/RSRA flight program. Also a set of slow- and high-speed taxi tests were conducted to investigate methods to improve yaw-control performance during ground roll on the X-Wing/RSRA. It was determined that by reducing the tail-rotor control-cable tension and removing the tail-rotor centering spring, there was a major improvement in handling qualities at low taxi speeds, but no measurable improvements at the higher speeds above 40 to 50 knots.

Flight data were also obtained during the year for the Rotor Force Derivatives/Parameter Indentification program for developing a methodology to improve mathematical modeling of rotor-system aerodynamics.

Preliminary data were obtained for the S-61 Performance program to verify new operating techniques and real-time data computations. The RSRA provides a unique set of rotor and fixed-wing load measurements which allows researchers to separate and vary the loads on the rotor system to explore more fully the rotor performance throughout its flight envelope. To arrive at a test point, the pilot must simultaneously control the rotor lift, drag, tip Mach number, and advance ratio.

(R. Kufeld and E. Seto, Ext. 5664)



Rotor Systems Research Aircraft (RSRA) in compound mode

Shake Test of a UH-60 Instrumented Rotor Blade

The objective of this program was to determine the model parameters and spatial model of a UH-60 instrumented rotor blade. The blade was suspended from its root end by soft bungee cords. The bungee cords and overall pendulum length of the suspension comprised a low-frequency suspension system which isolated the blade. Exitation, generated from an electrodynamic shaker, was applied to the blade root. Blade frequency-response functions were measured at 16-in. intervals for each mode and were used to estimate the mode shapes. The corresponding estimated modal dampings were from both single- and multiple-degree-of-freedom curve-fit algorithms of the structural measurement system (SMS) modal software.

With the known modal parameters, the frequency-response function matrix was estimated and used to estimate the mass, stiffness, and damping matrix. The nonrotating natural frequencies, corresponding modal damping, and

mode shapes were estimated. Listed below are the nonrotating frequencies and their damping ratios.

Mode	Nonrotating frequency, Hz	Damping, %
First flatwise	4.35	0.270
Second flatwise	12.55	0.090
Third flatwise	24.99	0.120
Fourth flatwise	41.63	0.140
Fifth flatwise	63.71	0.160
Fifth torsion	44.65	0.200
Second torsion	82.44	0.210
First chordwise	25.37	0.240
Second chordwise	67.39	0.140

The construction of the UH-60 blade spatial model is complete. With inputs from the known spatial model of the blade, the C-81 and CAMRAD will predict modal parameters under a variety of boundary conditions. Based on the information gained, the shake test was carried out with the simulated free-end boundary conditions.

(R. Kufeld and E. Seto, Ext. 5664)

Rotor Systems Research Aircraft/X-Wing Program

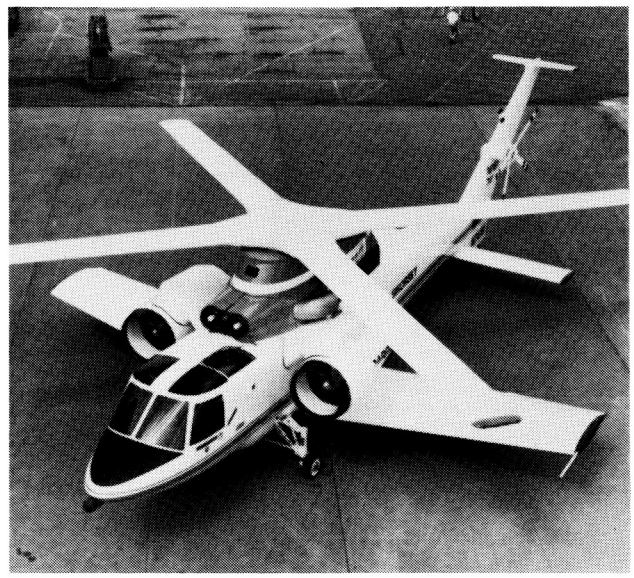
One of two Rotor Systems Research Aircraft (RSRA) is being modified at Sikorsky Aircraft to incorporate a four-bladed, extremely stiff rotor that can be stopped in flight. For takeoff, hovering, and low-speed flight, the rotor will function as a helicopter rotory wing. At a speed of about 200 mph, the rotor will be stopped and locked in place, making the aircraft a fixed-wing airplane with two forward-swept wings and two aft-swept wings in an "X" configuration. In the latter mode, it is expected that the RSRA will have a speed potential approaching 300 mph.

This research program (sponsored by NASA and the Defense Advanced Projects Research Agency (DARPA)) is to demonstrate conversion from the rotor-turning mode to stopped, fixed-wing flight, and back again. This demonstration, coupled with the successful completion of the NASA/DARPA Convertible Engine program and the DARPA/Army NOTAR program, would provide the necessary technology base to initiate an X-Wing prototype vehicle, capable of Mach 0.8 fixed-wing flight.

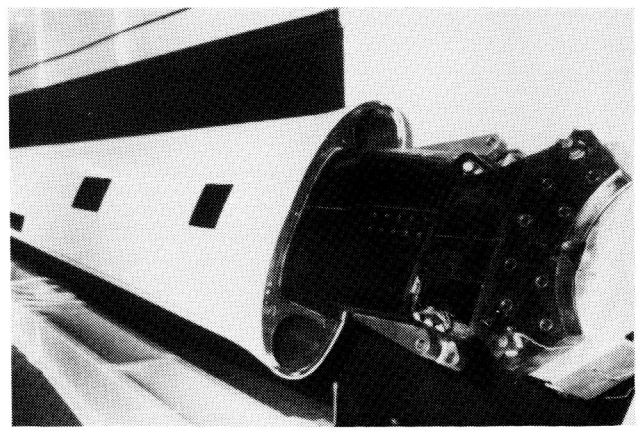
During this past year the Ames-Dryden Flight Research Facility (DFRF) was selected as the flight-test location for the RSRA/X-Wing aircraft.

In addition to completing assembly of the aircraft, six composite rotor blades have been successfully manufactured and will undergo certification testing for stopped-rotor flight. Additionally, the Emergency Escape System pyrotechnic blade-severance system was successfully developed and tested this past year. All four blades can be severed in flight by the pilot using ribbon charges fixed to the root section of each blade.

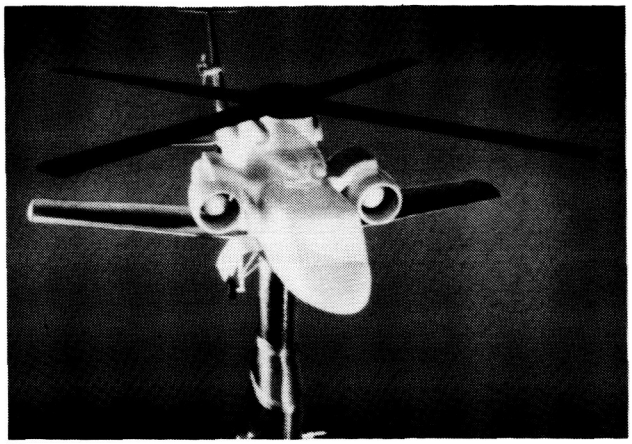
Full-power testing was conducted on the Propulsion System Test Bed (PSTB) using flight-like transmission, pneumodynamic components propulsion-drive systems (clutch, brake, etc.), and engines.



RSRA/X-Wing flight vehicle



Completed composite rotor blade



RSRA/X-Wing wind tunnel model

Initial testing of the powered wind tunnel model has been completed at the United Technology Research Center wind tunnel. Data have been gathered with the rotor off and in the stopped-rotor, no-blowing configuration. An externally complex 1/5-scale blade wind tunnel model is used to predict the rotor structural dynamics, pneumodynamics, and vehicle stability and control characteristics.

Manufacturing of the quad-redundant, digital Flight Control Computers (FCC) and hardware checkout was done during the past year. Initial testing with the FCC box interfaced in the Vehicle Management Systems Laboratory (VMSL) has been completed. Verification and validation of the FCC software has begun in the VMS, a simulator designed to test aircraft hardware and software prior to flight. A successful piloted simulation was also conducted in the Ames Vertical Motion Simulator.

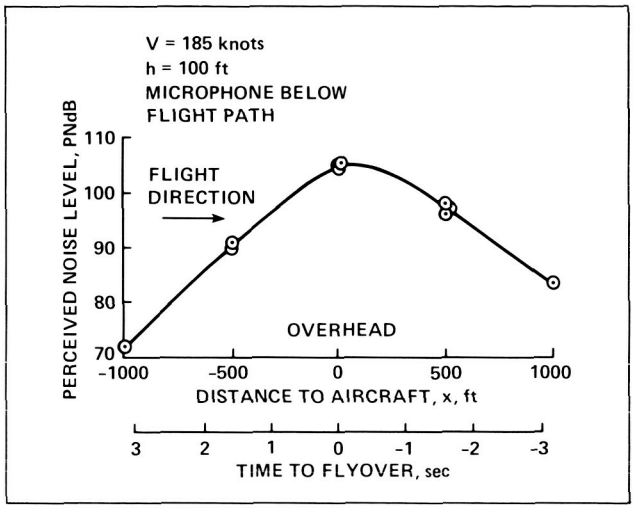
(P. Loschke and J. Lane, Ext. 6576)

Tilt-Rotor Aircraft Acoustics Research

A series of tests have been conducted to investigate the acoustics characteristics of tilt-rotor aircraft. The acoustic energy transmitted to the structure of the XV-15 Tilt-Rotor Research Aircraft was measured with microphones mounted flush with the skin surface and installed along the side of the fuselage in a longitudinal array. Additional microphones were placed in the cabin. Data were acquired for all flight modes, from hover through a 220-knot airplane-mode flight condition. The information obtained was provided to Boeing Vertol, Bell Helicopter, and NAVAIR to validate methodology, establish acoustic structural fatigue predictions, and to determine cabin acoustics levels for the NAVY V-22 Tilt-Rotor Aircraft.

Far-field noise measurements were obtained for flyover and approach conditions. In cooperation with Bell Helicopter, data were obtained for helicopter, tilt-rotor, and airplane-mode flyovers. Approaches were made at various nacelle angles, airspeeds, and glide slopes. The data will enable evaluation of low-noise terminal-area approaches and "good neighbor" operations for executive and commerical tilt-rotor aircraft. An example of the short duration and low noise level generated by the XV-15 during a 185-knot flyover is given in the figure.

(M. Maisel and J. Cross, Ext. 6372)



XV-15 Tilt Rotor Research Aircraft flyover noise history

Tilt-Rotor Download Investigations

The reaction of the rotor wake on the tilt-rotor aircraft airframe results in downward forces in the hover mode which significantly degrade hover performance. This "download" has therefore been the subject of a series of investigations aimed at improving the comprehension of the complex three-dimensional flow phenomenon, generating quality flight-test data for the validation of analytical methods, and developing practical approaches to reduce download, and thereby improve hover performance. NASA has previously

teamed with the Army in two wind tunnel tests of two-dimensional wings at near -90° angle of attack and in a flow-visualization study of a tilt-rotor model.

Recent efforts in this area with the XV-15 Tilt-Rotor Research Aircraft include a hover test (both in ground effect (IGE) and out of ground effect (OGE)), a tiedown test to calibrate rotor-thrust indicating parameters, and a tiedown flow-visualization test. The wing upper surface flow-visualization results showed that conditions varied markedly along the wingspan, from chord-wise flow near the tips, to nearly spanwise flow inboard. The spanwise flow results in an upward turning of the air mass above the fuselage (into what is called a "fountain") where the flows from the two rotors collide. This fountain is estimated to be responsible for about one-third of the download force. Future efforts will include in-flight evaluations of download-reducing devices.

(M. Maisel and L. Schroers, Ext. 6372/5456)

Flow-visualization study of hover-mode rotor wake near wing-tip of XV-15 on tiedown stand

Tilt-Rotor Advanced Technology Blade Flight Investigation

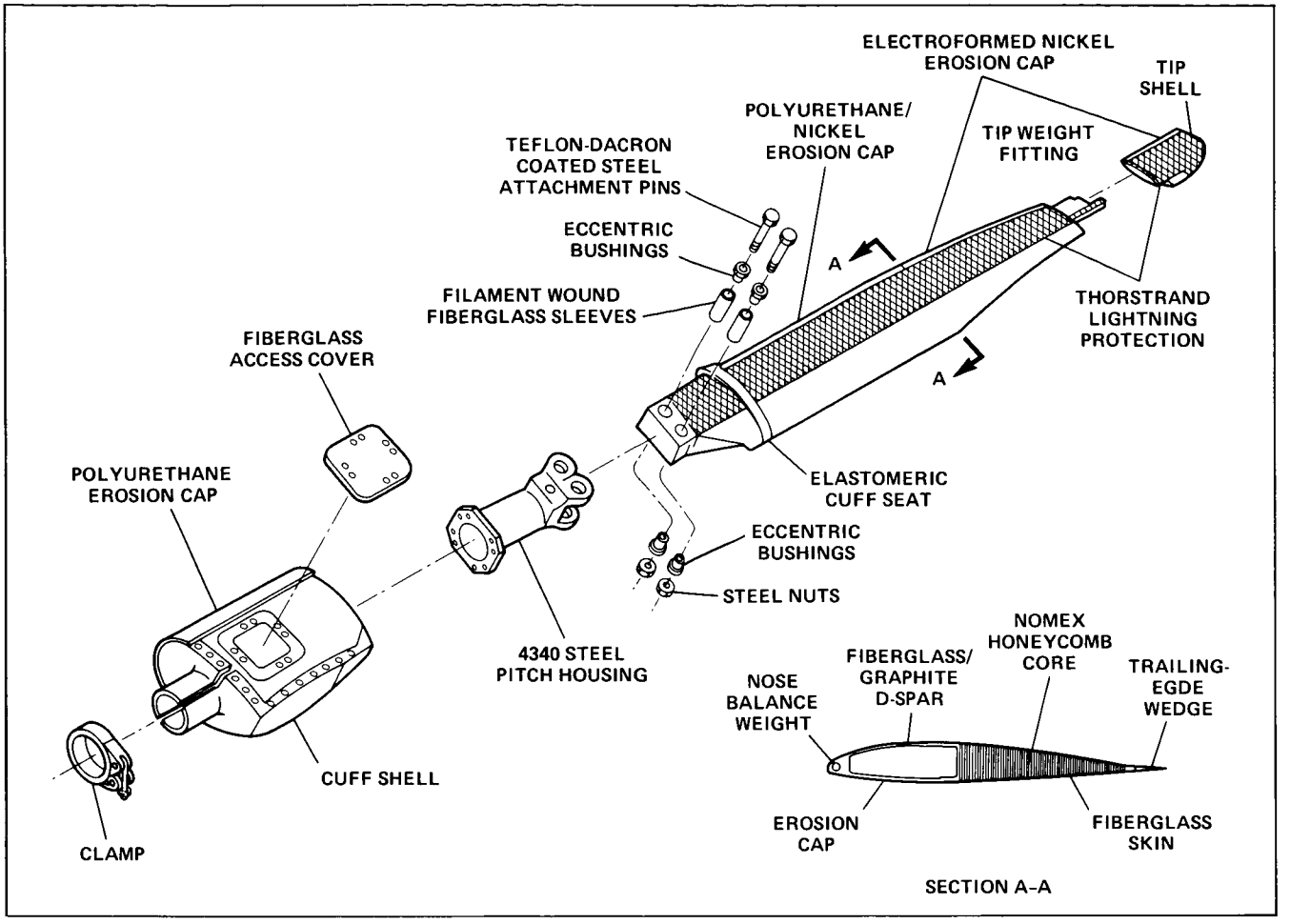
All composite, advanced-technology rotor blades (ATB) for the XV-15 Tilt-Rotor Research Aircraft have been fabricated by Boeing Vertol under contract to Ames Research Center. The ATB are the first flightworthy rotor blades to incorporate a recently developed high-strain graphite. The successful completion of the blade specimen's static and fatigue tests has led to the recent selection of the ATB high-strain graphite/fiberglass/epoxy system for application to the rotor blades for the Navy V-22 tilt-rotor aircraft.

The advanced-technology blades were designed to increase the high gross weight, hover-mode thrust capability without degrading the high-speed, airplane-mode performance of the XV-15. A combination of state-of-the-art airfoil sections (Boeing VR-7 and VR-8), a high twist, and a nonlinear tapered planform are employed to achieve the aerodynamic trade-off between the conflicting high-speed and hover-mode requirements.

An additional research feature of the ATB is the ability to alter the geometry by replacing the removable tip and cuff sections. Work was initiated in 1986 to fabricate an alternate set of flightworthy tip covers and cuff components.

Flight testing and evaluations of the baseline ATB on the XV-15 began during the last quarter of FY 1986.

(M. Maisel and W. Snyder, Ext. 6372)



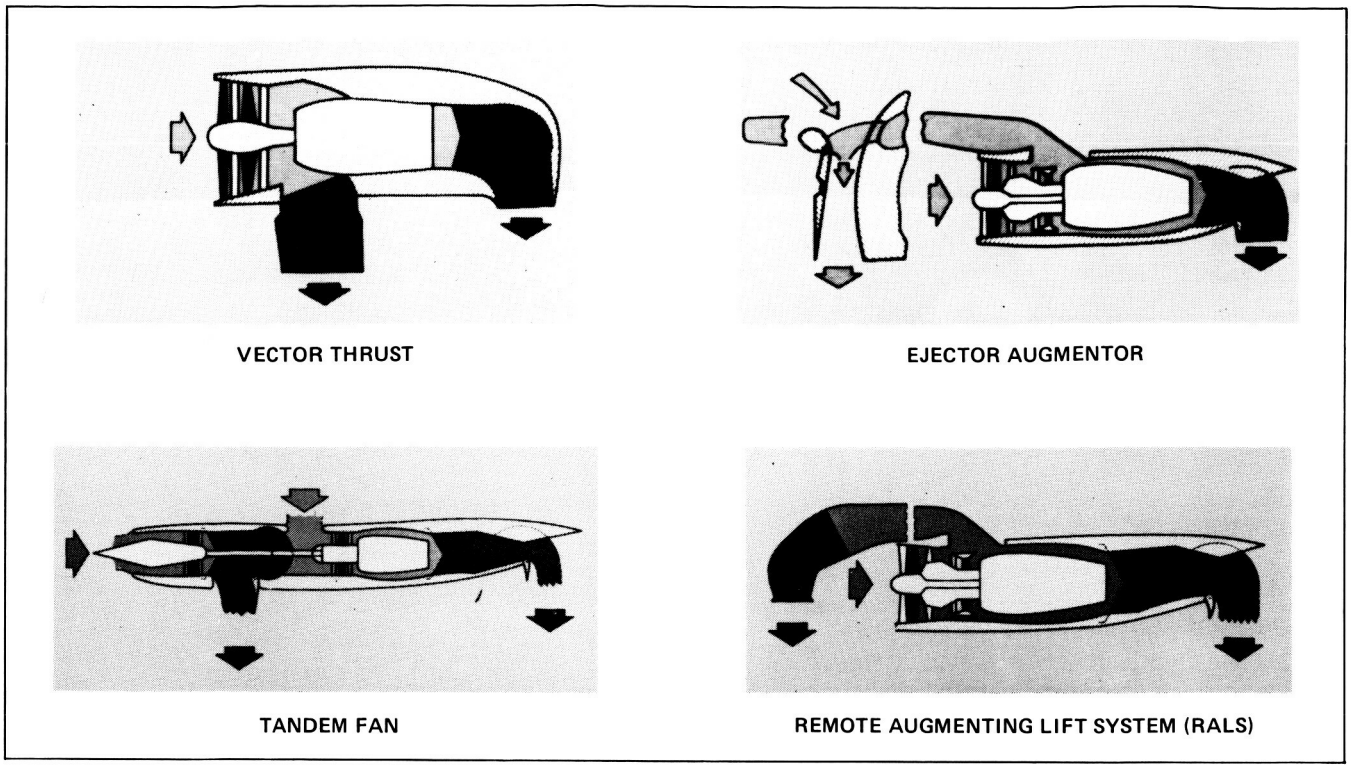
Components of the ATB rotor blades

U.S./U.K. Advanced Short Takeoff and Vertical Landing Aircraft Technology Program

The governments of the U.S. and the U.K. are cooperating to further the technology for a supersonic, advanced, short takeoff and vertical landing (ASTOVL) fighter aircraft. This cooperative effort (the U.S./U.K. ASTOVL Aircraft Technology program) involves the U. S. Department of Defense, the National Aeronautics and Space Administration, the U.K. Ministry of Defense, and the U.K. Royal Aircraft Establishment. Government teams have been established to focus on the definition of a joint U.S./U.K. technology program for ASTOVL concepts. The intent of this program is to mature those concepts sufficiently to judge their relative merits, and to support future program decisions, including the possibility of a flight demonstrator/research aircraft.

This ground-based technology program is covered by a Memorandum of Understanding (signed by both governments in January 1986) which is for 5 yr. with 1986 as the first year. The program focuses on a single-engine, single-seat, supersonic STOVL fighter/attack aircraft with excellent transonic maneuverability and an all-weather capability. Four promising propulsion concepts which have been identified as potentially feasible for this type of aircraft are featured in this program: vectored thrust, ejector augmentor, remote augmented-lift system, and tandem fan (shown in the figure).

There are three elements in the U.S./U.K. ASTOVL program: (1) concept-evaluation studies, (2) common technology programs, and



Supersonic STOVL propulsion concepts

(3) concept-specific technology programs. The concept-evaluation studies have contracted efforts to provide:

(1) Four aircraft configuration definitions, each featuring one of the four propulsion concepts;
(2) Aircraft mission performance, including sensitivities;
(3) Identification of critical technologies, including sensitivities; and
(4) A definition of ground-based technology-development plans, including an indicative cost estimate for conducting these plans.

These concept studies are being conducted in the U.S. and the U.K. with no collaboration between contractors to provide two independent assessments of the relative merits of the concepts.

Thus, collaboration in this element will be solely between Government officials. In the U.S., there are four engine studies and four airframe studies, one for each of the propulsive lift concepts. Lewis Research Center is handling the engine contracts, and Ames Research Center is handling the airframe contracts. Proposals have been received and evaluated for both the engine and airframe contracts covering all concepts, and both activities are on schedule. The engine studies began in October 1986 and the airframe studies are to start in January 1987. The studies are 1 yr in length. These studies will aid in the down-select process to narrow the concepts from four to some lesser number.

The common technology element of the program features research efforts to develop technology that is applicable to more than one of the ASTOVL concepts. The seven common technologies that have been identified and the responsible NASA Centers are:

1. Ames: Hot-gas reingestion; ground erosion; integration of flight/propulsion controls
2. Lewis: Fan air collector, valves and ducting; augmentation by burning; thrust-deflector-nozzle technology
3. Langley: Jet-plume/aircraft-structure interactions

Efforts to formulate joint U.S./U.K. programs in these areas are under way. Two "quick start" activities have been identified and joint plans are being made in the areas of flight/propulsion controls at Ames and jet plume/aircraft structure interactions at Langley.

The concept specific technology element of the program features research efforts to develop technology that is unique to a given ASTOVL

concept. These would be initiated after the concept studies and down-select process are completed. An example of a concept-specific technology would be the aerodynamics of a configuration in ground effect, in transition, and in up-and-away flight. The approach to both the common and concept-specific technology elements of the program is to encourage international industrial collaboration.

(P. Nelms and D. Riddle, Ext. 6093/6085)

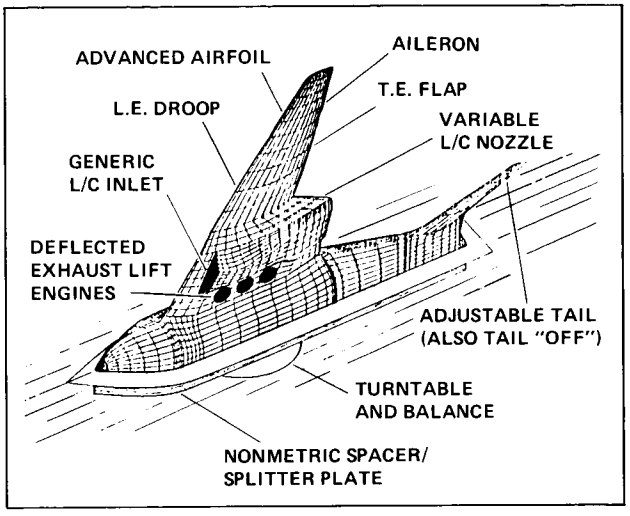
Advanced Tactical Transport Technology

There is a renewed Air Force interest in developing a military advanced tactical transport (ATT) aircraft to be introduced in the mid-to late-1990s. Evolving Air Force mission requirements may dictate that this airplane possess V/STOL field performance capability or, at the very least, STOL characteristics superior to those demonstrated during the YC-14 and YC-15 prototype programs. Combining these stringent field-performance requirements with superior cruise efficiency will require the meticulous blending of vehicle aerodynamics, propulsion integration, and stability and control technologies. A well-developed analytical capability will be used to the fullest extent possible during the configuration development cycle. However, experimental data must be acquired in the hover and transition flight regimes in order to quantify the performance level of these advanced-technology transport concepts.

Under a Memorandum of Understanding between Air Force Wright Aeronautical Laboratory (FI) and Ames Research Center a cooperative program is under way to define and assess several V/STOL military tactical-transport concepts which meet multiple mission requirements. The starting point for the program is the AFWAL/FIA lift-plus lift-cruise transport design. With Air Force financial support, Ames personnel are designing and fabricating a 7%-scale semispan model for testing in the ARC 7- by 10-Foot Wind Tunnel in March 1987. A VSAERO analysis of the configuration has been completed, predicting forces, moments, and pressures. The wind tunnel data for the hover and transition flight regimes will be acquired and analyzed. Design guidance has been provided for advanced airfoils and the wind tunnel data will be used to verify the computed characteristics.

Additionally, Ames and AFWAL/FI will develop an alternate V/STOL transport configuration which uses a propulsive lift system other than lift-plus-lift-cruise. Assessment has begun on the potential of an upper-surface-blowing (USB) configuration for superior STOL and VTOL. Ground measurements have been made of the USB flap flow field on the Ames Quiet Short-Haul Research Aircraft (QSRA). These data are being used to design and fabricate a modified flap for a series of ground tests to determine augmented USB flow-turning efficiencies for VTOL operations.

(D. Riddle and P. Nelms, Ext. 6085/6093)



Advanced tactical transport

Airloads of Modern Single Rotor UH-60 Black Hawk

Ames Research Center, in cooperation with the Aeroflightdynamics Directorate-AVSCOM, has initiated programs to investigate the aerodynamics performance limitations of modern rotors at high speeds, in maneuvers, and at low speeds. These investigations are being undertaken to promote a better understanding of basic rotor aerodynamic and dynamic phenomena, and to support near-term developments, such as experimental light helicopters (LHX). Tasks include systematic flight research to investigate blade air loads for noise and vibration.

The initial flight phase, which will support LHX, uses an Army UH-60. The later phases of the program are focused on obtaining comprehensive in-flight rotor air-loads measurements

for providing a national rotor data base using a special set of highly instrumented UH-60 blades.

A joint Army/NASA flight investigation is in progress. The instrumentation installation is essentially complete. The compilation and correlation of the comprehensive analytical model of rotorcraft aerodynamics and dynamics (CAMRAD) input data with other developed rotorcraft prediction programs have been completed. The CAMRAD dynamic and load predictions are now being acquired. The highly instrumented blade fabrication has been initiated and risk, the reduction blade specimen for investigating instrumentation wiring and pressure transducer installation techniques, is almost complete.

(E. Seto and J. Cross, Ext. 5664/6571)

Modern Technology Rotor Airloads Program, BV-360

The Modern Technology Rotor (MTR) Airloads Program is a key element in the NASA-Army effort to enable the development of helicopters with improved performance, reduced loads and vibrations, and reduced acoustics signatures. Specific objectives include the measurement of high-speed rotor performance, dynamic loads, and high-frequency-content airloads, and the validation of comprehensive prediction codes.

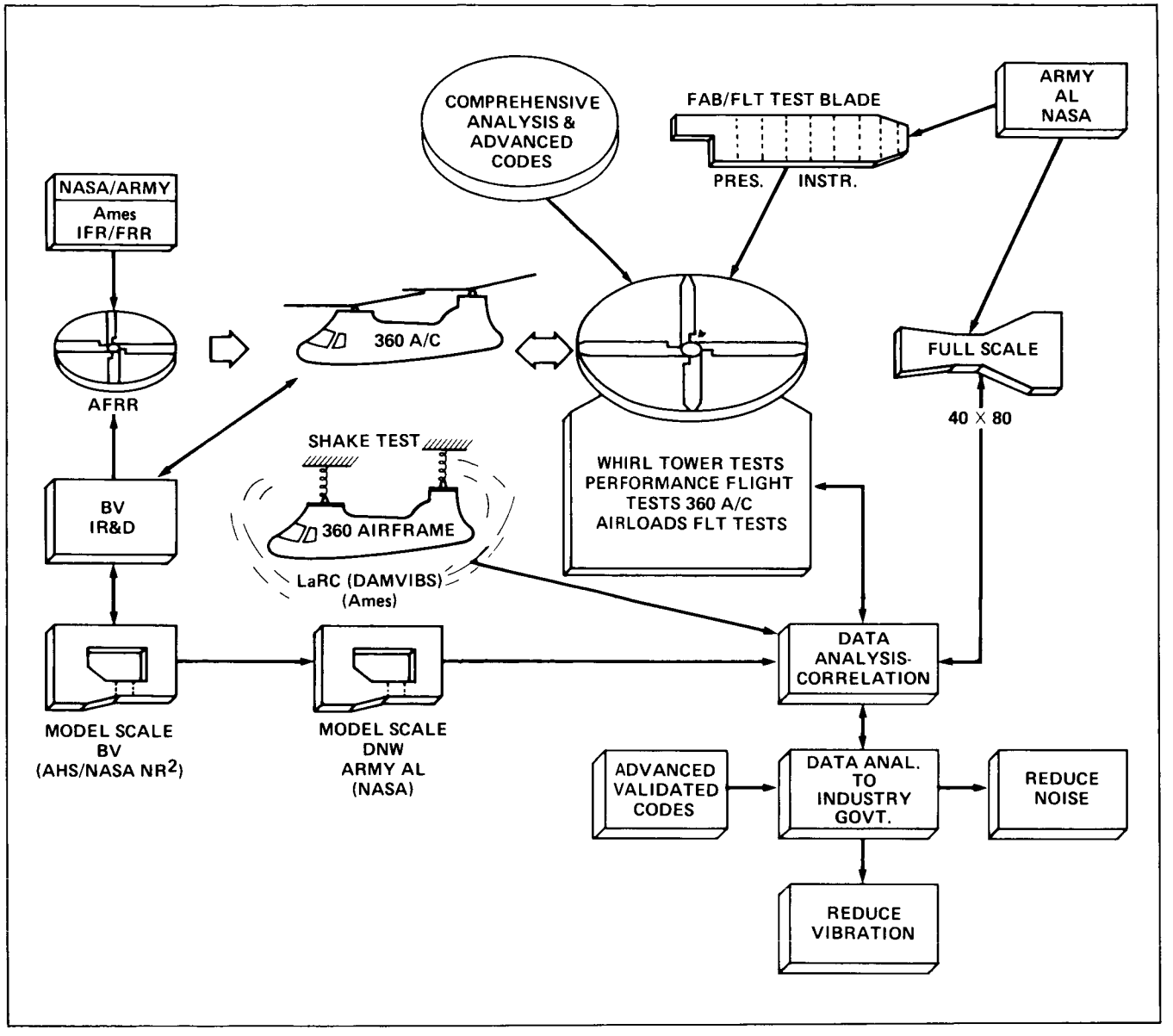
The investigation will focus on the forward rotor of the Boeing Vertol Model-360 helicopter, a tandem helicopter now under development. The selection of that rotor was based on the predicted level speed capability of over 200 knots, and the new technology incorporated in the composite blade design (such as the advanced airfoils and the tailored planform). The blades for the 49.7-ft-diam. forward rotor were completed in 1986 are are scheduled to be whirl-tested by Vertol during the last quarter of the year. The Model-360 helicopter is nearing completion and flight-testing is expected to commence during the first quarter of 1987. The initial flight data will document the performance and dynamic characteristics of the rotor and aircraft.

Model scale tests of the -360 forward rotor were conducted in 1986 to obtain baseline data in the areas of performance, dynamics, and airloads for establishing scale effects through correlation with the results of the planned full-size flight and wind tunnel tests. The scale model airloads test was performed at the Deutsch-Niederlandischer Windkanal as a joint Army/NASA/Boeing/Netherlands program.

The development of a flightworthy full-scale blade equippped with over 200 pressure transducers was initiated this year. In addition, a data-acquisition system is being developed at Ames which is capable of acquiring the large volume of high-frequency airloads data in the rotating system and transmitting a series of digital bit streams to the on-board recorders.

Analytical studies conducted under this program include the prediction of rotor loads and moments for airspeeds up to 200 knots. Two codes, the NASA-developed comprehensive analytical model of rotorcraft aerodynamics and dynamics (CAMRAD) and the Vertol-developed C-60 program were applied to establish preflight estimates.

(W. Snyder and M. Maisel, Ext. 6570/6372)



NASA/Army modern technology rotor airloads program

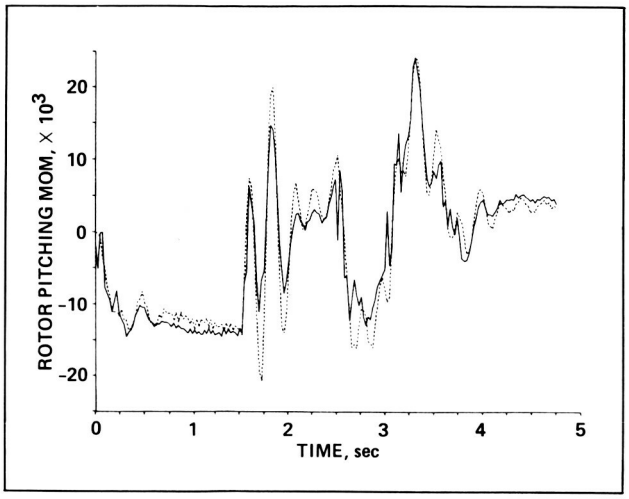
Rotor Force Derivatives and Parameter Identification

During the past year, analysis and simulation of the Rotor Systems Research Aircraft (RSRA) compound helicopter have been conducted to develop a methodology for making linear estimates of rotor motions and loads as functions of perturbations in the rotor and fuselage degrees of freedom. The load measurements are made possible by the RSRA rotor-balance system. The application of parameter identification methods to the simulation model indicated that identifying rotor-force derivatives from flight data is quite feasible, and provides information on a maneuvering rotor which is not normally available from wind tunnel tests.

Flights experiments were conducted to provide test cases for application of these methods. These consisted of 3-2-1-1 and doublet inputs into each control axis at a trimmed speed of

100 knots. Processing of these results is currently under way. The compound results will be compared directly with identified six degrees-of-freedom results obtained earlier in the year on the fixed-wing configuration.

(P. Talbot, and J. Wang, Ext. 5108)



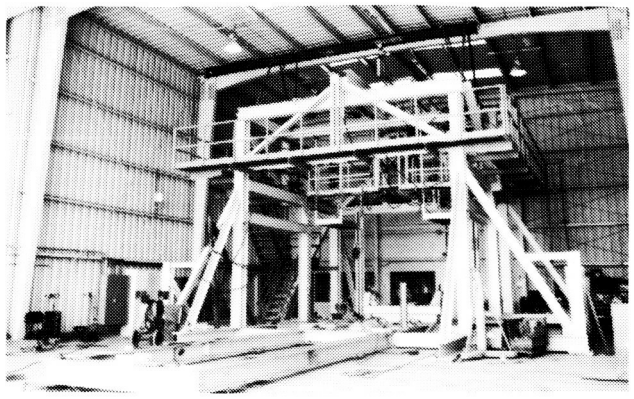
Comparison of nonlinear simulation with identified linear model - rotor pitching moment

Rotor Systems Research Aircraft Calibration Facility

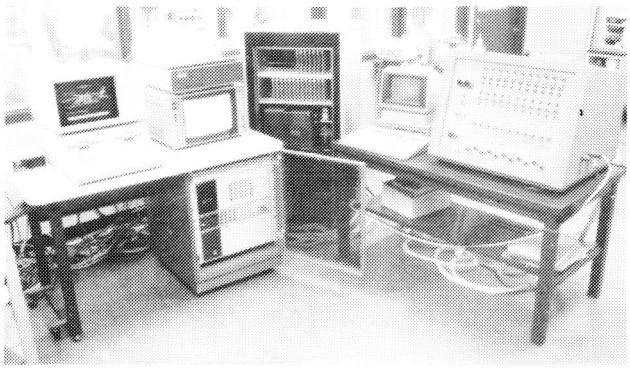
Architectural improvements to the Rotor Systems Research Aircraft (RSRA) Calibration Facility have been essentially completed, adding 4000 ft^2 of hangar space to the building. This addition will allow the high bay to accommodate the RSRA in its winged compound configuration, and will shield the aircraft completely from solar radiation and wind loads.

The third-generation data-acquisition and control system is in place and complete. This is an automatic/semiautomatic/manual, computer-controlled/servo-force feedback system for precision load application, to circumvent problems noted during previous calibrations. The final checkout and acceptance is to proceed after reassembly of the test apparatus. Solutions to the problems noted during proof testing earlier this year will be verified prior to calibration of the RSRA.

(J. Wellman and F. Baker, Ext. 6573)



Calibration facility architectural improvements nearing completion



Third-generation computer-controlled load application systems

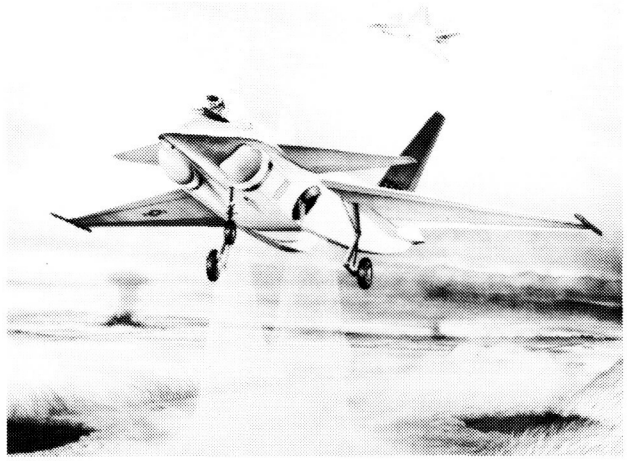
Study of a Hybrid Tandem Fan Vectored Thrust Supersonic STOVL Fighter Aircraft

Lockheed-California Co., under contract to Ames Research Center, is conducting a study of aerodynamic technology for single-engine, hybrid fan vectored thrust (HFVT) supersonic STOVL fighter/attack aircraft. The study is to enhance and expand aerodynamic, airframe, and aerodynamic/propulsion interaction technology for this type of aircraft, which would operate in the year 2000 time period. The study consists of two phases: Phase I concept identification and analysis task, and Phase II wind tunnel model design, fabrication, and test program.

In the Phase I study task, the contractor conducted a conceptual design analysis based on government-provided guidelines and a design mission chosen by the contractor. Sensitivity and trade-off studies and performance evaluations

were completed for the proposed configuration, which is shown in the figure. An analysis of the proposed configuration included ground effects, hot-gas reingestion, powered-lift effects, and maneuver and cruise performance. Detailed estimates of the longitudinal and lateral/directional aerodynamic characteristics were provided. Aerodynamic and aerodynamic/propulsion interaction areas of uncertainty were identified, and a research program directed toward resolving these uncertainties was recommended by the contractor. Phase I has been completed, and the final oral review was held at Ames on September 18, 1986. A contract will be awarded for Phase II in early FY 87, with significant participation by Defense Advanced Research Projects Agency.

(C. White and P. Nelms, Ext. 4054/6093)

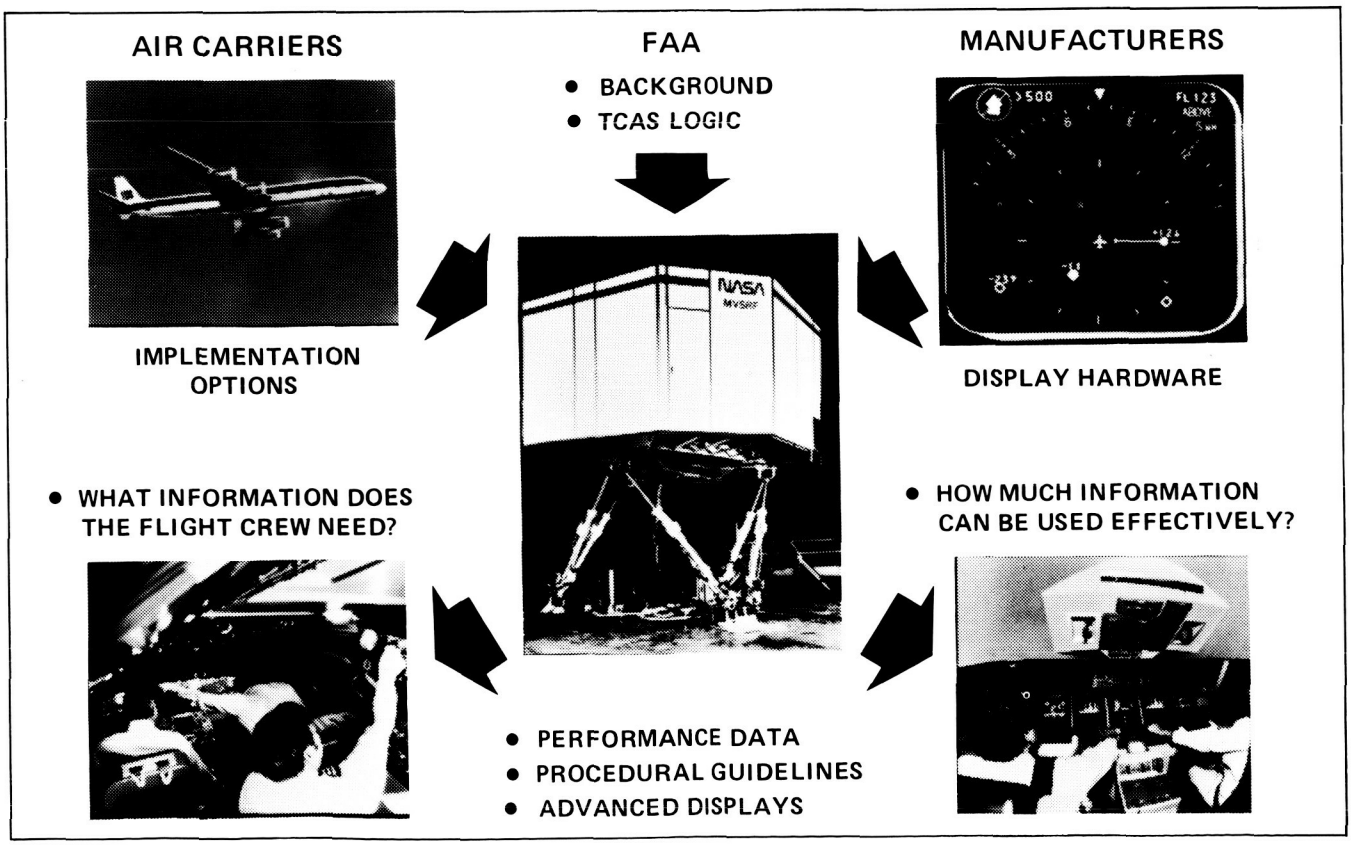


Hybrid fan vectored thrust supersonic STOVL fighter aircraft

Traffic Collision-Avoidance System Information Transfer

Ames Research Center is working in collaboration with the Federal Aviation Administration (FAA) to study information transfer using the FAA's newly developed TCAS II system. The project involves close cooperation among avionics industry manufacturers, airlines, the Air Transport Association, the FAA, and NASA.

The first experiment in this program makes use of equipment made available by industry, TCAS algorithms provided by MIT's Lincoln Laboratories, displays which may be used by airlines



Traffic Collision Avoidance System (TCAS)

taking part in the FAA's Limited Implementation Program (LIP), and line flight-crew members provided by Air Transport Association (ATA) member carriers. Ames is implementing a realistic full-mission flight and Air Traffic Control (ATC) simulation involving multiple, standardized, traffic encounters under a variety of conditions of crew workload, weather, and other pertinent factors. The principal independent variable is the amount of information to be provided to flight crews concerning traffic encounters. The crews will be evaluated with respect to their responses to the TCAS traffic information, their ability and willingness to utilize standardized procedures, and the communications and other workload in the cockpit and ATC system caused by the TCAS environment.

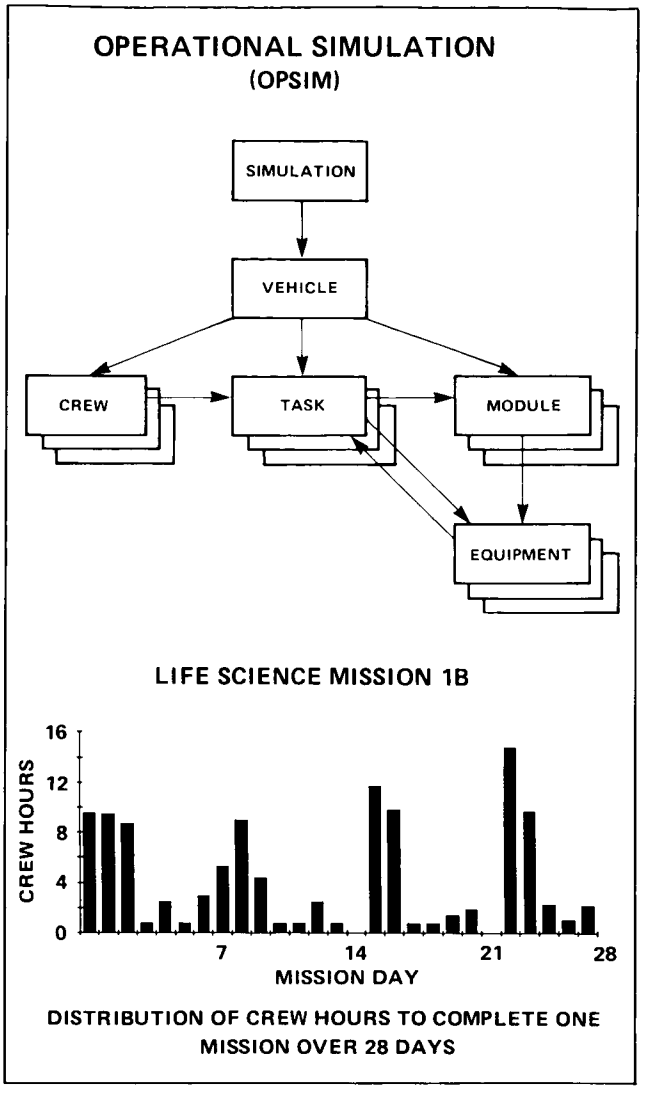
After review of the scenarios by experts from the operational community, data collection will occur during the first quarter of FY 87. The results will provide the FAA with further data on crew responses to standardized and repeatable traffic conflicts, and the air carriers participating in the LIP with performance data which can be used to guide their training of pilot participants in the program. The insights gained in this initial study will guide subsequent research into appropriate TCAS displays for advanced aircraft utilizing electronic flight decks.

(C. Billings and S. Chappell, Ext. 5718/6909)

Space Station Operational Simulation

The Space Human Factors Office at Ames Research Center has developed Operational Simulation (OpSim), a computer modeling tool for simulating Space Station operations. This tool is to provide a means to identify and resolve Space Station operational problems at low cost through simulation. The focus of the simulation is crew activities, although equipment, consumables, and power consumption are also modeled. Crew tasks, skill levels, and intravehicular activity movement are modeled, as are equipment contention, failure, and repair. The user interface is such that automation studies are particularly well supported.

The first version of OpSim was made available to the Space Station community in December 1985. Twelve NASA and contractor sites received copies of the software. In one study, the non-



Distribution of crew hours to complete one mission over 28 days

human life-science group at Ames used this version of OpSim to study crew and automation requirements for several potential Space Station missions. The second version of OpSim, with significantly expanded functionality, is now available.

OpSim uses two computers, an Apple Macintosh for the user interface and a VAX/UNIX for simulation. Data are entered on the Macintosh using a unique commercial data base management system that associates data records with graphical objects in a diagram. The data are transferred to UNIX for simulation by software developed by the Space Human Factors Office and the results are returned to the Macintosh for analysis using a commercial, integrated software application. The

simulation is implemented using object-programming technology, a relatively new approach to software development with great promise for Space Station application. To decrease user costs and operational complexity, the simulation will be ported to the Macintosh, eliminating the need for VAX/UNIX and inter-computer file transfer.

The chart contains two diagrams. The first is the structure of the data used to represent the major elements of Space Station operations — vehicles, modules, equipment, crews, and tasks. The second is a graph of some of the data generated by the Ames study showing the number of crew hours required each day for the first 28 days of a particular nonhuman Life Science mission.

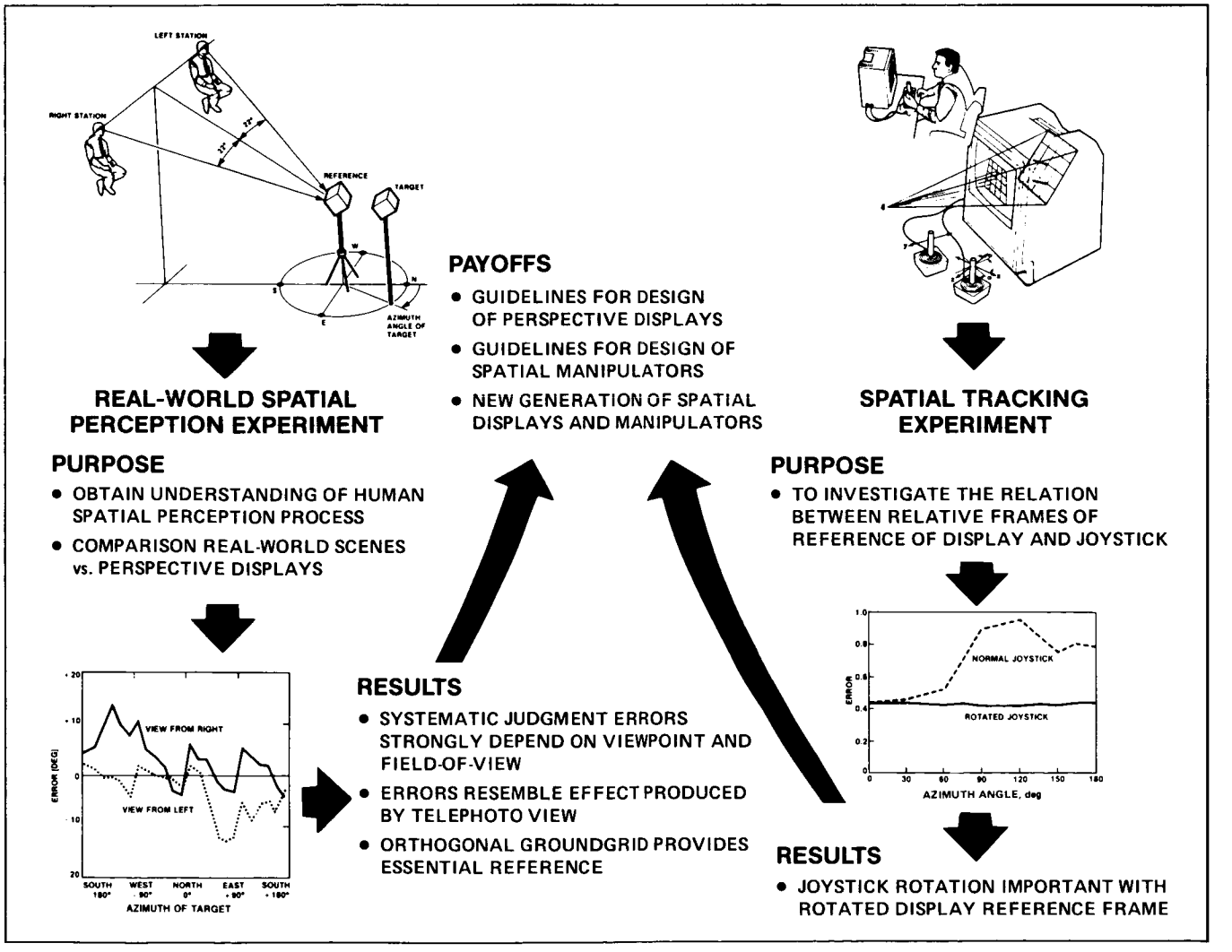
(Y. Clearwater, Ext. 5937)

Spatial Perception and Spatial Displays

The basic goal of the spatial perception research project is to develop an understanding of the human spatial perception process which enables the researcher to perceive and control objects in three-dimensional (3-D) space.

Understanding the limitations and capacities of human spatial perception has assisted in the formulation of rational guidelines and recommendations for the definition of various spatial instruments to be used in space and aircraft operations.

Three experiments have been completed concerning pilots' abilities to judge depicted directions both on perspective displays and in actual real-world scenes. Two additional experiments



Spatial perception studies

have been completed and reported concerning subjects' ability to control the 3-D position of an object when it was displayed in a rotated reference frame.

The results of these experiments have refined earlier theoretical explanations of errors in direction judgments, and improved the earlier guidelines and recommendations for display definition.

The presence of an orthogonal groundgrid on which the projection of various spatial objects was shown was found to be an essential spatial reference in perception from perspective displays. It was also found that a wide-angle view tended to reduce systematic direction judgment errors. The spatial tracking experiment showed the usefulness of rotating the joystick when the display reference frame was rotated. This information has been made available to aerospace contractors.

(S. Ellis and A. Grunwald, Ext. 6147)

Virtual Workstation

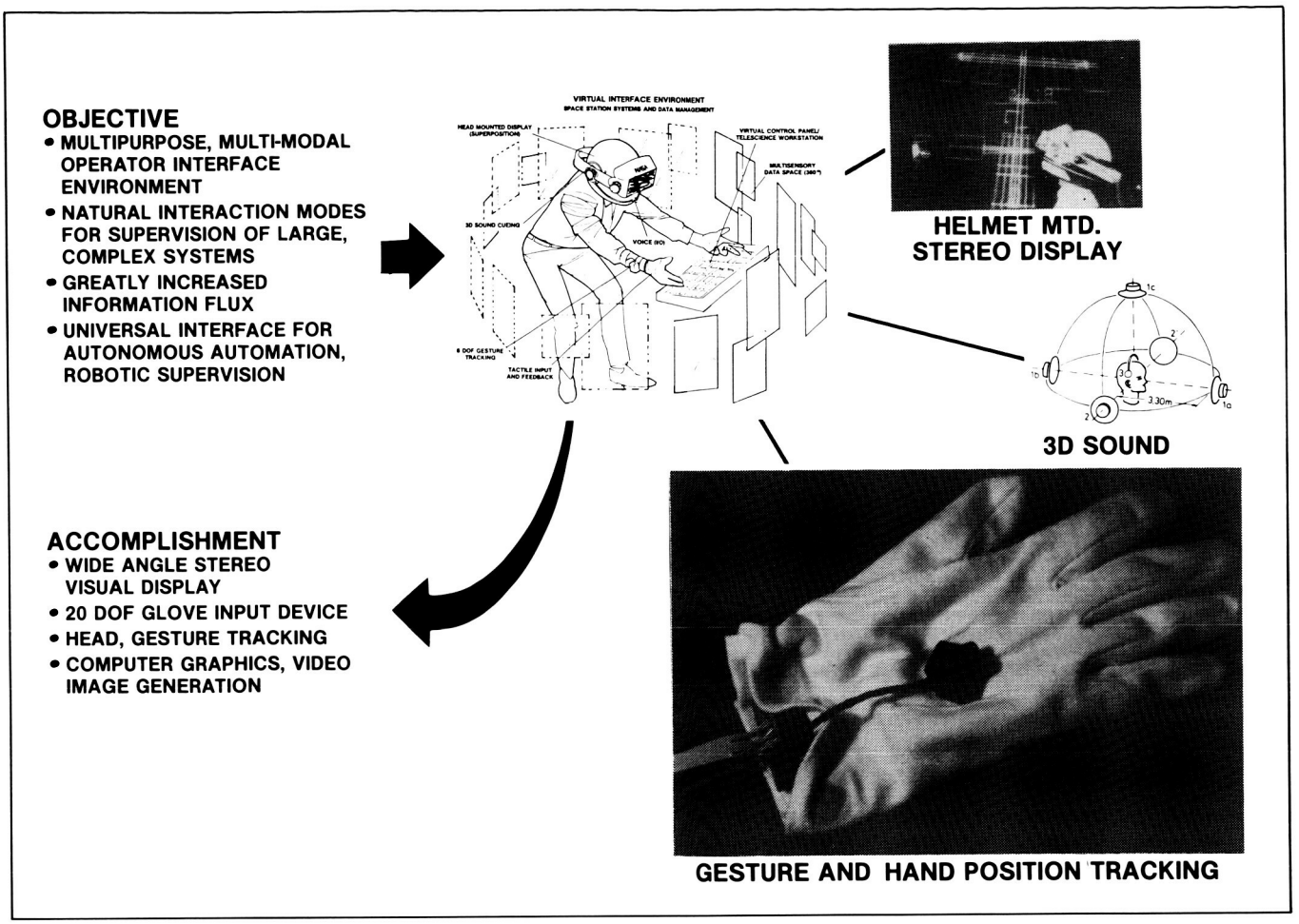
This research is intended to develop a multipurpose multimodal operator interface to facilitate natural interaction with complex operational tasks, and to augment operator situational awareness of large-scale integrated systems (autonomous and semiautonomous). Performance in such task environments requires an operator interface configuration that features human matched displays and controls for transparent, natural system interaction and reduced training requirements. A head-mounted, wide-angle, stereoscopic display system controlled by operator position, voice, and gesture has been developed to meet these requirements. With this interface configuration, an operator can virtually explore a 360° synthesized or remotely sensed environment and viscerally interact with its components. Primary space-application areas include: (1) complex operational tasks such as control of remotely operated robotic devices and vehicles that require a sufficient quantity and quality of sensory feedback to approximate actual presence at the task site, (2) extravehicular activity (EVA) image display and multimodal information management systems, and (3) interaction with large-scale integrated information systems in which data manipulation, storage and retrieval, and system-monitoring tasks can be spatially organized.

An additional research objective includes use of this display system to synthesize interactive test environments for aerospace human-factors research in such areas as spatial habitability research, rapid prototyping of display and workstation configurations, research on effective transfer of spatial information, and spatial cognition research on multisensory integration.

The current virtual workstation system consists of a wide-angle stereoscopic display unit, glove-like devices for multiple-degree-of-freedom tactile input, connected speech recognition technology, gesture tracking devices, and computer-graphic and video-image generation equipment. The head motion of the user is tracked by a helmet-mounted sensor and the derived position and orientation data are used to update the displayed stereo images in response to the user's activity. As a result, the displayed imagery appears to completely surround the user in three-dimensional (3-D) space and contains full motion parallax, motion perspective, and binocular paralled information. To interact with the displayed 3-D environment, the user wears lightweight glove-like devices that transmit data records of arm, hand, and finger shape and position to a host computer. In coordination with connected speech-recognition technology, this information is used to effect indicated gestures in the synthesized or remote environment. Current applications of voice and gesture mediated interaction are in the control of robotic arms and end-effectors. Similarly, in the virtual data-management environment, multiple windows of information and simulated control panels are positioned, sized, and activated in 3-D space.

Near-term technology developments include high-resolution, color-display elements, integration of 3-D auditory display technology for spatially correspondent, synthesized sound cueing, tactile feedback capability, multiple viewing display interaction, and multiple display units for shared workspace configurations.

(S. Fisher, Ext. 6789)



Virtual interface environment

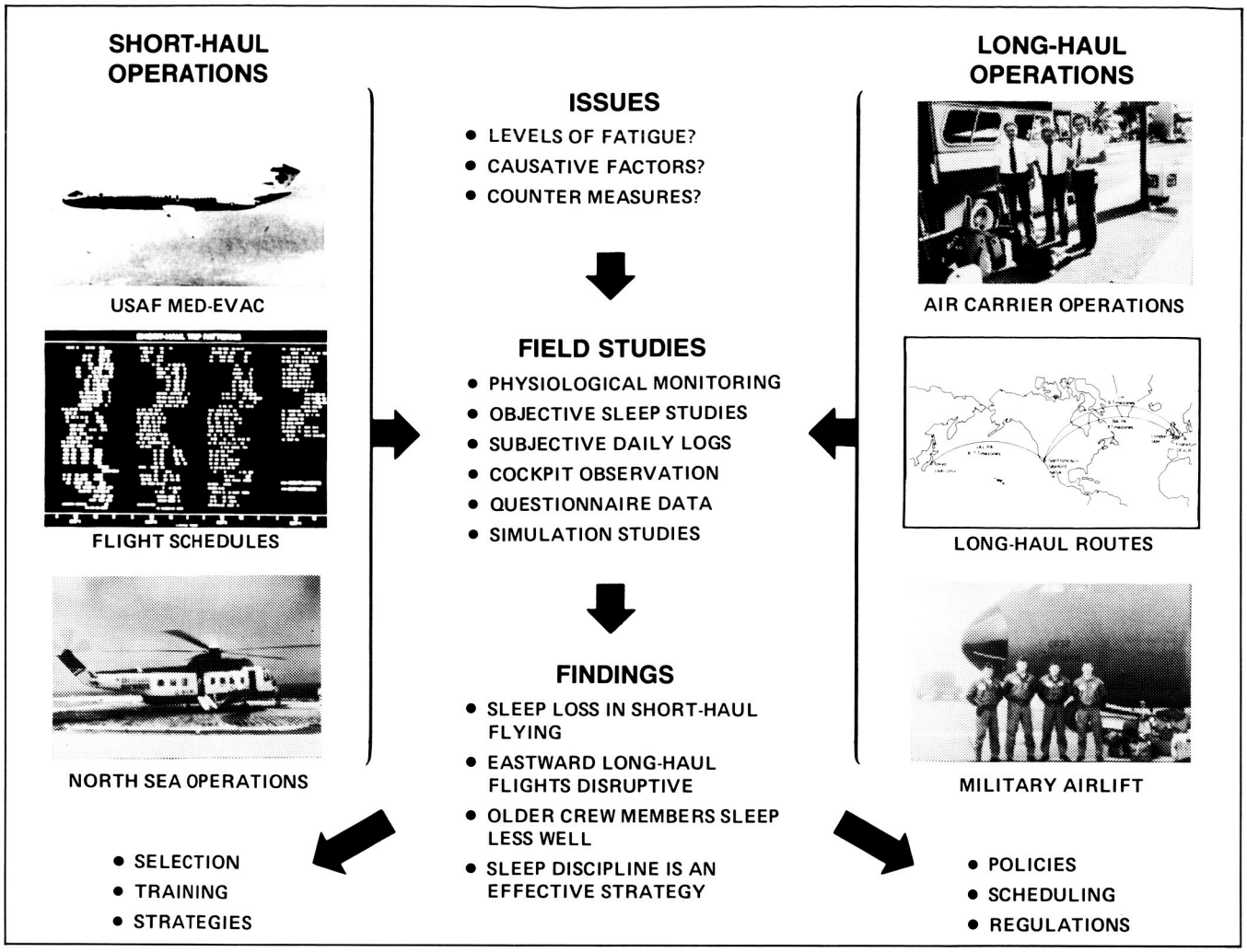
Flight Crew Fatigue and Jet Lag

Fatigue is often cited as a significant factor in pilot performance. Field studies are being conducted to determine the extent to which flight crews experience fatigue and circadian dysrhythmia (jet lag) during scheduled flight operations. Also, individual factors and behaviors are being identified which may exacerbate or moderate such effects.

Volunteer crews undergo continuous physiological monitoring of heart rate, body temperature, and activity, before, during, and after trips lasting 3 to 8 days. These records are supplemented with time-linked cockpit observer logs of pertinent operational events. Individual factors are documented by combining background, personality, and lifestyle information with daily logbooks in which sleep activities, diet, and mood are recorded.

Civilian and military crews are being studied in a variety of aircraft flying short- or long-haul patterns. Trip selections are based on number of flights per day, trip and layover length, unusual flight times, airspace density, time-zone crossings, and direction of flight. Collaboration with foreign laboratories and airlines has provided additional electroencephalogram (EEG) data on crew sleep and alertness after multiple time-zone flights and physiological data on helicopter pilots flying in stressful environments. Parallel laboratory research is being used to test the effectiveness of jet-lag countermeasure proposals.

The various studies are in different stages of completion, ranging from published reports to ongoing data collection; however, several consistent findings are already emerging. Regardless of the type of trip, crews usually seem more poorly during layovers away from home, especially after flying eastward across multiple time zones.



Flight crew fatigue and jet lag

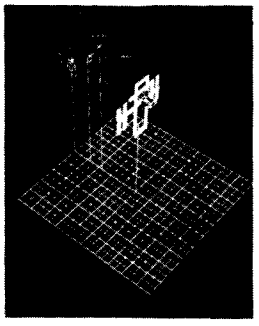
Increasing age exacerbates this effect, especially after age 50. The decrease in the amount and quality of sleep is reflected in subjective mood and fatigue during flight duty. Individual differences observed in response to the same trips are quite large and are partly the result of differences in personality and lifestyle. Both field and laboratory data indicate that sleep discipline can be employed effectively as a countermeasure after certain types of multiple time-zone flights.

(C. Graeber, Ext. 5792)

Integrated Rendezvous and Proximity Operations Displays

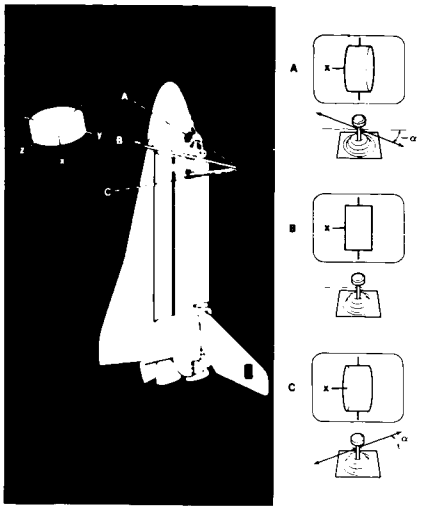
The purpose of this research program is to provide candidate display concepts for Space Station proximity operations displays and for the JPL Telerobot Demonstrator. The display concepts will emphasize the use of metrical computer graphics to present spatial information to astronauts or operators of a space station.

A prototype of the display format has been implemented in the Ames Research Center proximity mockup (APOM). This display demonstrates the use of perspective computer graphics to present astronauts with predicted flightpath, planned flightpath, and attitude information needed to plan and execute proximity operations



PAYOFFS

- FLEXIBILITY IN OPERATIONS
- TIME/FUEL OPTIMIZED MANEUVERS
- CLEAR ASSESSMENT OF COMPLEX TRAFFIC SITUATION
- EASE OF OPERATION
- REDUCED WORKLOAD
- INCREASED SAFETY



PROTOTYPE PROX OPS DISPLAY

- PERSPECTIVE PRESENTATION OF COMPLEX SPATIAL SITUATION
- SHOWS PREDICTED/PLANNED SPATIAL FLIGHT PATH
- USES METRICAL COMPUTER GRAPHICS
- EASILY INTERPRETABLE FORMATS

TELEROBOT OPERATIONS

- INTEGRATED CONTROLS AND DISPLAYS
- EFFICIENT AND DIRECT MANIPULATOR CONTROL
- NATURAL INTERACTION WITH MANIPULATORS AND DISPLAYS

Integrated rendezvous and proximity operations displays

and docking maneuvers. Various improved versions of this display are being developed and evaluated on an IRIS 2400 Turbo workstation.

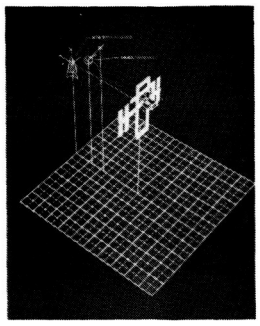
Several experiments are planned in the APOM which will be coordinated with other laboratory experiments to explore the usefulness of advanced computer graphics to present orbital, rendezvous, and proximity operations information in an integrated format. The perspective display formats will enable a clear and effective presentation of a complex spatial traffic situation around the Space Station. The displays will provide the flexibility to perform optimized maneuvers without elaborate preflight planning. The emphasis in the developments will be on the ease of use, the reduction of human operator workload, and increased flight safety.

(A. Grunwald and S. Ellis, Ext. 6147)

Proximity Operations Mockup

Proximity operations in the vicinity of the International Space Station will eventually become complex and a critical part of the operations of the overall station system. The operations will involve vehicles, platforms, and extravehicular manned units (EMU), all of which will require monitoring and control. Before the proximity operations control system can be defined, a number of important questions must be addressed. These involve manual versus automated operation, questions of the locus of control, and issues surrounding the design and function of the workstation on the Space Station itself.

Ames Research Center has developed and studied several critical technology components for a proximity operations workstation over the past several years. Perspective displays, voice I/O systems, supervisory control interfaces, spacecraft windows, and head-up displays have all received systematic attention. The new proximity operations mockup at Ames integrates these into a reconfigurable, mission-oriented simulation of the proximity operations workstation and operating



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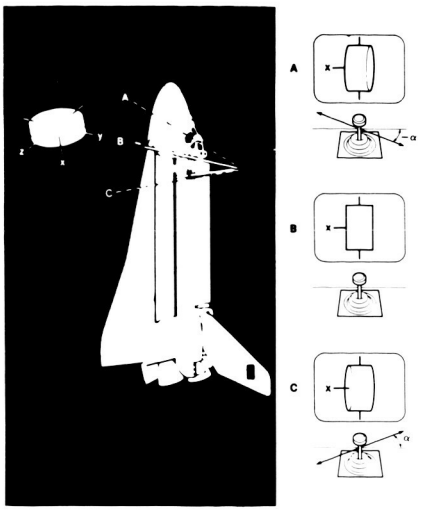

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OBJECTIVE

FACILITY TO SUPPORT STUDIES OF SPACE STATION ARCHITECTURES, CREW STATIONS, OPERATIONAL ISSUES

ACCOMPLISHMENT

- RECONFIGURABLE MOCKUP, FORM AND FUNCTION
- PROVIDES HARD DATA FOR SPACE STATION DECISIONS
- INTEGRATES OAST TECHNOLOGY INTO FUNCTIONAL SPACE STATION CREWSTATIONS
- PROVIDES HIGH FIDELITY OPERATIONAL CONTEXT FOR CREWSTATION RESEARCH

Proximity operations mockup

environment. The mockup is now fully operational and will support human-systems, operations, and other studies germane to the design and operation of the Space Station system.

In addition to the development of the workstation itself, a user survey of potential users within and outside the Agency has been completed. This survey indicates a high level of interest in access to this new research facility at Ames.

(R. Haines, Ext. 5719)

Computer-Aided Workload Prediction for Rotorcraft

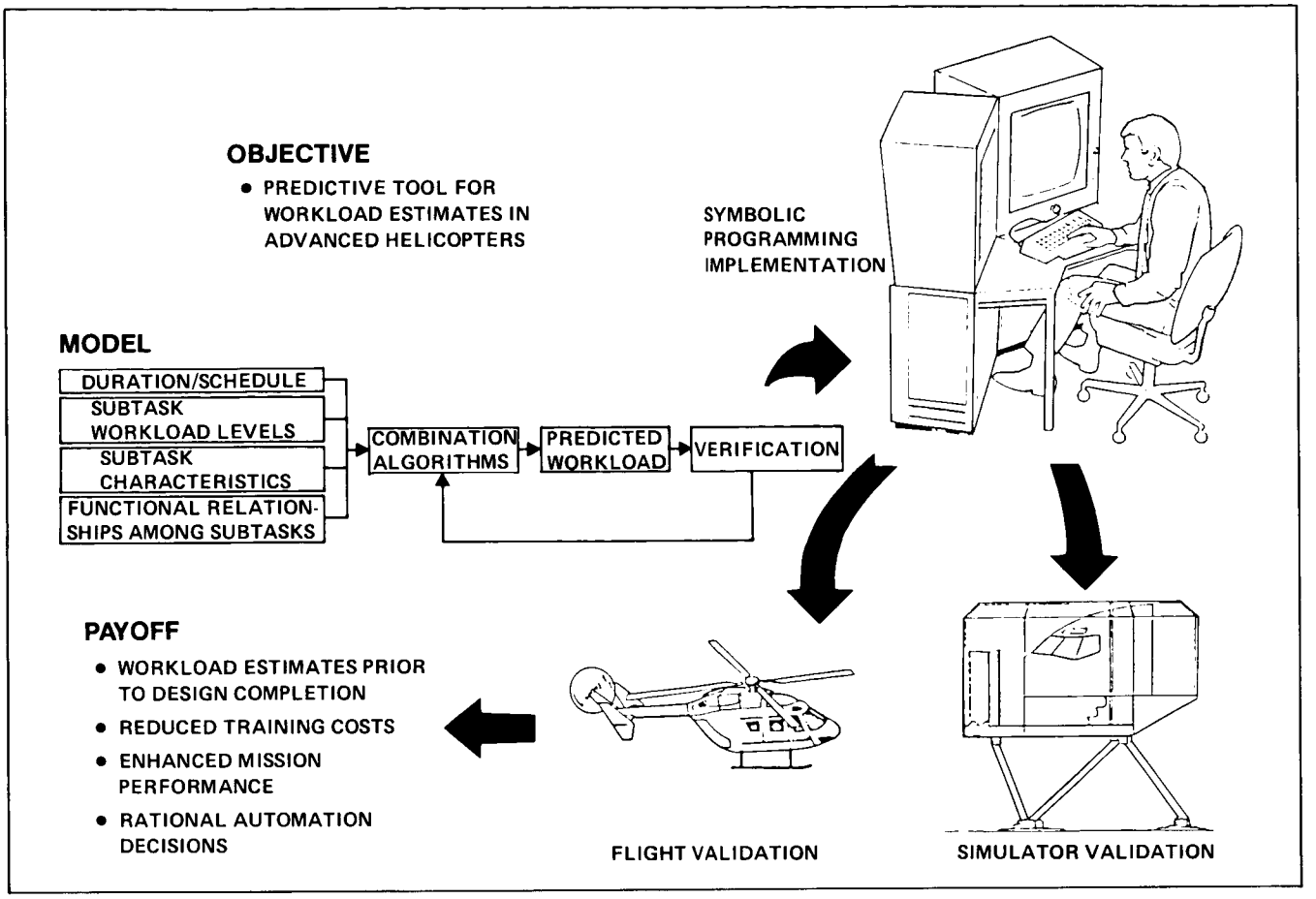
The Ames Research Center's workload assessment program began in 1982. The goal of the program was to develop standardized, reliable, and validated methods of assessing and predicting pilot workload. The first few years of this program were devoted to understanding the factors that influence pilot workload, evaluating existing assessment techniques, and developing new and improved techniques, where appropriate. The work was accomplished through an active cooperation between government laboratories, industry research groups, and universities.

The first phase of this program has been essentially completed. The factors that contribute to pilot mental workload have been identified, and a set of practical and reliable measures have been developed. Ames is now actively engaged in applying the results of the research to operational problems posed by the Army, civil operators, and industry, in part to assist in the solution to these problems, and in part to validate the measures and techniques developed to date.

Experience workload is the integrated product of many factors in addition to the objective demands that are placed on the pilot. The Ames approach has been to start with nominal or typical flight segments or mission elements. Information about their duration, intensity, and visual, auditory, information processing, and manual-control requirements is obtained and individual workload components are estimated for each of these. The functional relationships among the tasks associated with specific flight or mission segments are defined so that the appropriate workload combination algorithms can be applied to produce an integrated workload measure for the combined task load.

During FY 86, a preliminary version of the computer-aided workload prediction was developed and tested. The full model is under development on a Xerox 1108 using the PROLOG symbolic language.

(S. Hart, Ext. 6072)



Computer-aided workload prediction for rotorcraft

In-Flight Validation of NASA Workload Measures

Since 1982 NASA's comprehensive workload-assessment program has been focused on developing an understanding of the factors which contribute to the mental and physical workload of the pilot, and a valid and reliable measurement technology for both assessing and predicting the workload of pilots under operational conditions.

The resulting measures and methods have been used in a variety of settings, including several studies on the vertical motion simulator (VMS) at Ames Research Center, the recent advanced rotorcraft technology integration (ARTI) industry simulations of advanced helicopter configurations, and in-flight studies of North Sea oil operation pilots. The ideas have also been used in the development of the course syllabus for the Army's MANPRINT Program.

In FY 86, a comprehensive validation study was performed in the NASA SH-3G helicopter. The flight scenarios included straight and level flight above 3000 ft and contour flight, visual landings at an auxiliary site, instrument landings at airfields, hover in and out of ground effect, visual search patterns, and visual and instrument navigation conducted between Moffett Field and Crows Landing.

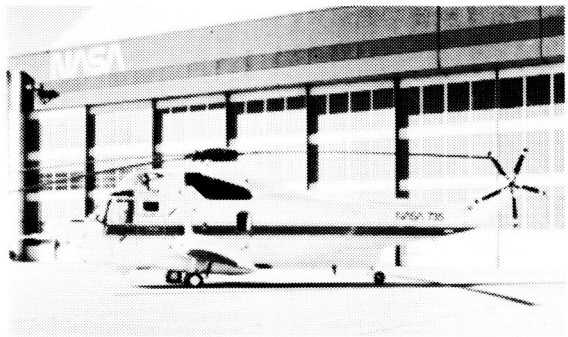
The workload measures under examination include pilot ratings, using the standardized Ames assessment procedures, secondary task performance, heart rate and heart rate variability, communication patterns, and other selected performance measures.

Interrelationships between the various measures will be quantified and compared, in part to measure the reliability of the various workload measures, and in part to begin the difficult task of establishing performance correlates with the measured workload and workload criteria.

(S. Hart, Ext. 6072)

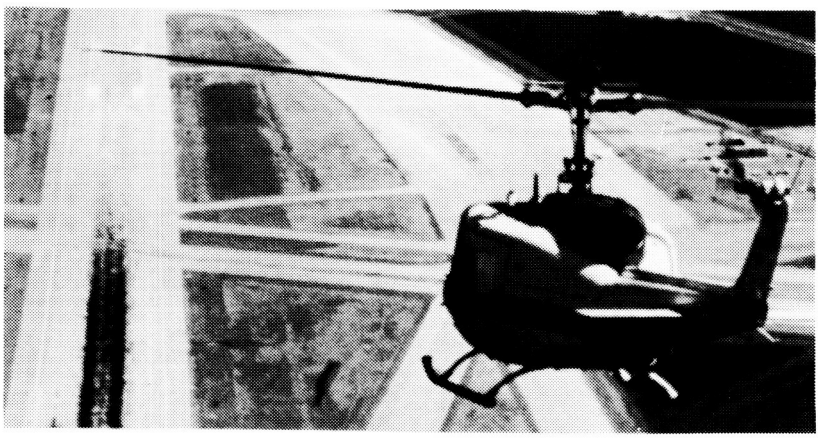
OBJECTIVE

DETERMINE THE SENSITIVITY AND OPERATIONAL VALIDITY OF WORKLOAD MEASURES DEVELOPED AT NASA-Ames



APPROACH

- CONSTRUCT SCENARIOS USING WORKLOAD PREDICTIVE MODEL
- SIX CREWS PERFORM TWO DIFFERENT FULL-MISSION SCENARIOS IN SH-3G
- COMPARE MODEL PREDICTIONS TO EMPIRICAL RESULTS



MEASURES

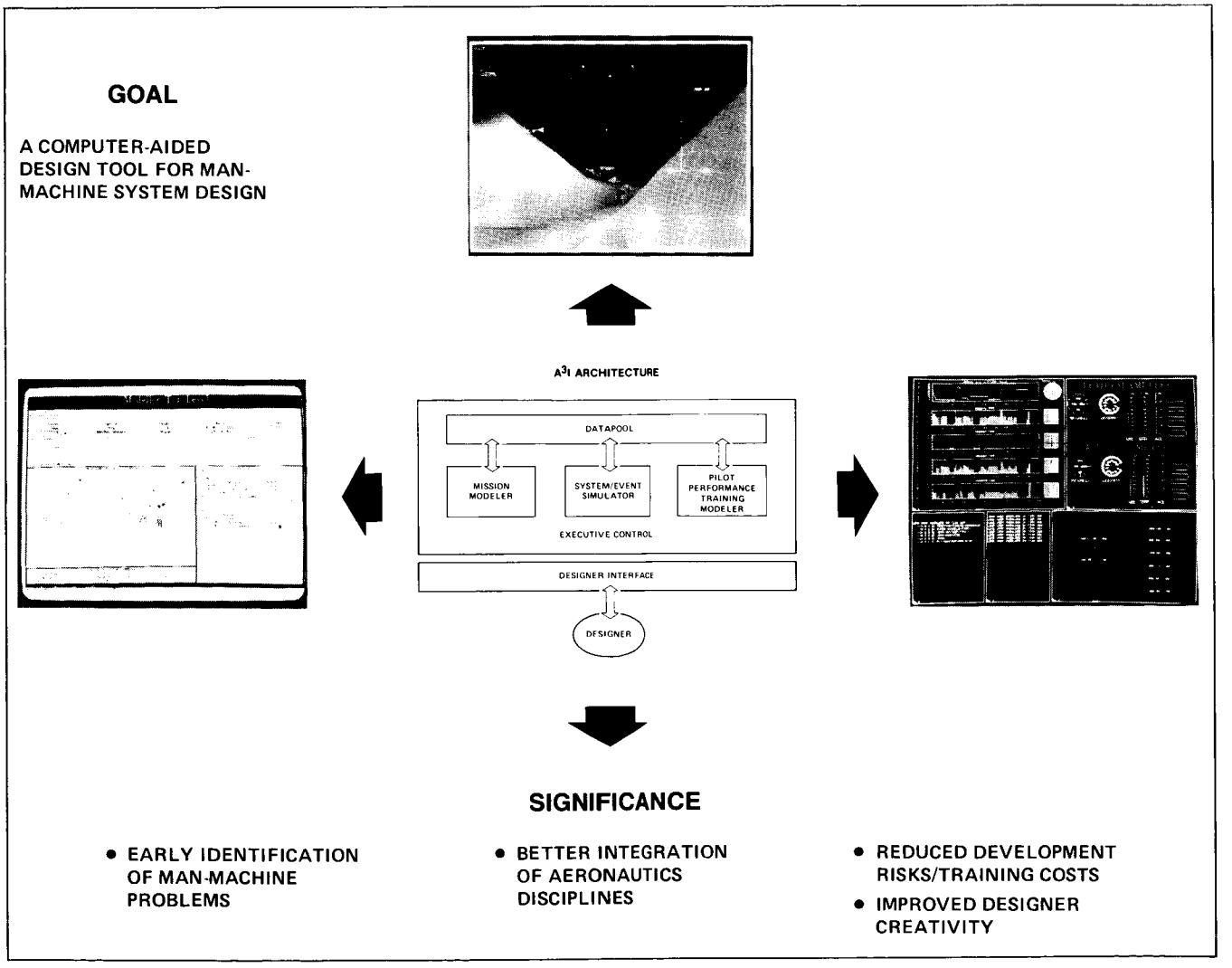
- PERFORMANCE
  - COMMUNICATIONS
  - CONTROL VARIABILITY
  - ERRORS
  - SECONDARY TASKS
- PHYSIOLOGICAL
  - HEART RATE
  - HEART RATE VARIABILITY
- SUBJECTIVE
  - NASA RATING SCALE

In-flight validation of NASA workload measures

Army-NASA Aircrew/Aircraft Integration

The Army-NASA Aircrew/Aircraft Integration (A^3I) program is an Army-NASA exploratory development program with the purpose of developing a predictive methodology for helicopter-system design, including mission requirements and training-system implications, that integrates human-factors engineering with other vehicle/system design disciplines at an early stage in the development process. The program will produce a prototype human factors/computer aided engineering (HF/CAE) workstation for use by design professionals. The interactive environment will include computational and expert systems for the analysis and estimation of the impact of cockpit design and mission specification on system performance by considering the performance consequences from the human component. The methodology developed to achieve the goals of the A^3I program may be generalized as a paradigm for the development and planning of a variety of complex, human-operated systems.

During FY 86, an initial version of the A^3I workstation was developed. An extremely flexible and powerful mission editor/planner system has been implemented on a hardware system consisting of a Symbolics 3670 connected via Ethernet to a Silicon Graphics Turbo Iris graphics workstation. A solid model and rendering software system has also been developed that allows the designer to visualize the mission as it progresses from several points of view, including that of the



Army-NASA aircrew/aircraft integration program (A^3I)

simulated pilot. Primitive human-performance models have also been incorporated into the system to demonstrate the utility and power of the concept. Near-term activities during FY 87 will include a rapid prototyping system for cockpit architecture and controls and displays, and second-generation human-performance models. A series of workshops will be conducted by the National Research Council for NASA on human operator modeling and its applicability to computer-aided design and engineering.

(E. Hartzell, Ext. 5743)

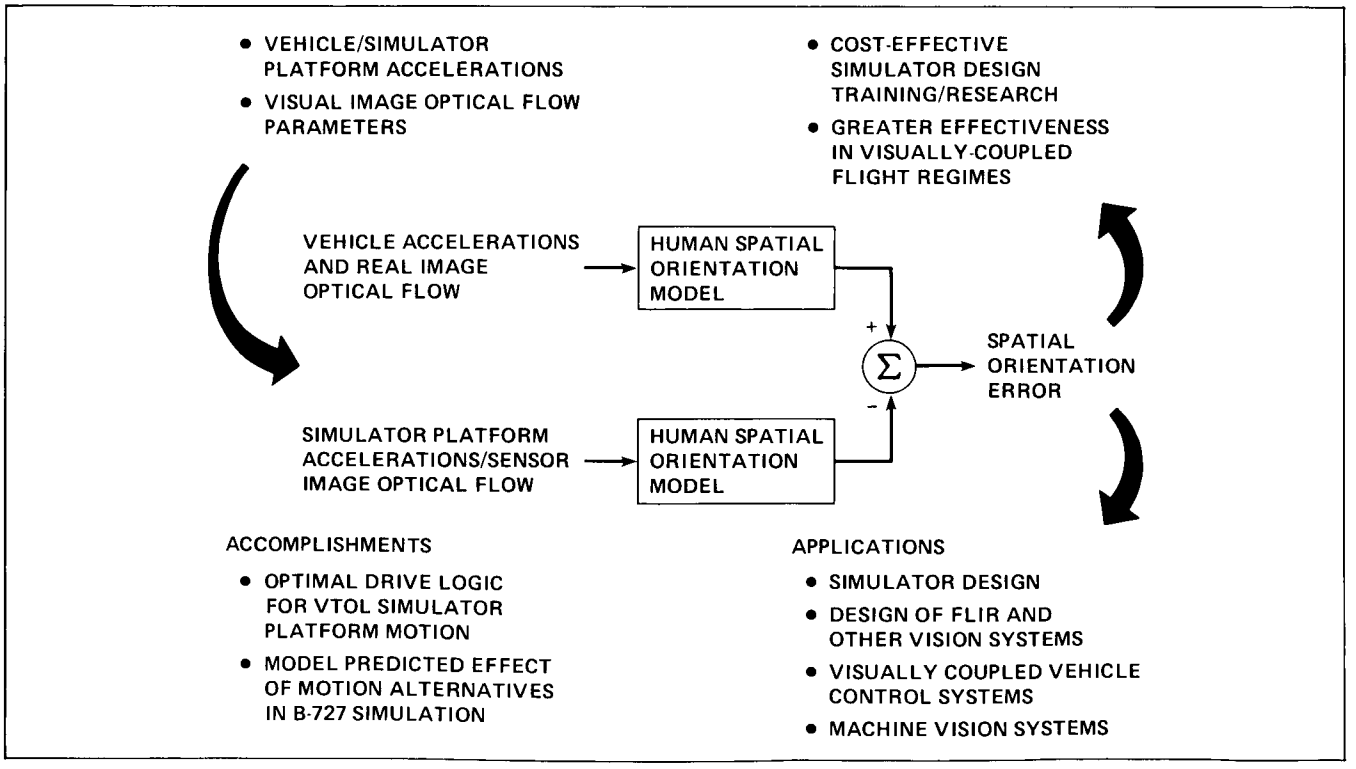
Human Orientation Model

In a cooperative effort with the Massachusetts Institute of Technology, Ames Research Center is engaged in the development and evaluation of a general utility engineering model of the human orientation system. The goal of this effort is to provide quantitative estimates of the effects of system design on human motion perception. The model is designed to determine human responses to a variety of system-induced motion conditions, including those provided by ground-based, simulator motion platforms, variations in vehicle dynamics, and visually coupled systems such as the forward-looking infrared (FLIR) system.

Thus far, the model has demonstrated its viability in recent validation tests of simulator platform motion design. In a comparison of a model-generated motion drive logic to other drive systems, subjective pilot ratings and performance in a vertical motion simulator (VMS) VTOL reveals that the drive logic was equivalent or superior to commonly used simulator drive logics. In an evaluation of alternative platform motion configurations for an air-transport flight-training simulator (MVSRF-B727), performance and subjective ratings conformed to those predicted by the model.

Future plans include the expansion and validation of the model to permit applications in the areas of visually coupled flight-systems design (e.g., FLIR), to simulator visual-system design, and to vehicle-handling problems associated with limited visual field-of-view and image data.

(A. Lee, Ext. 6908)



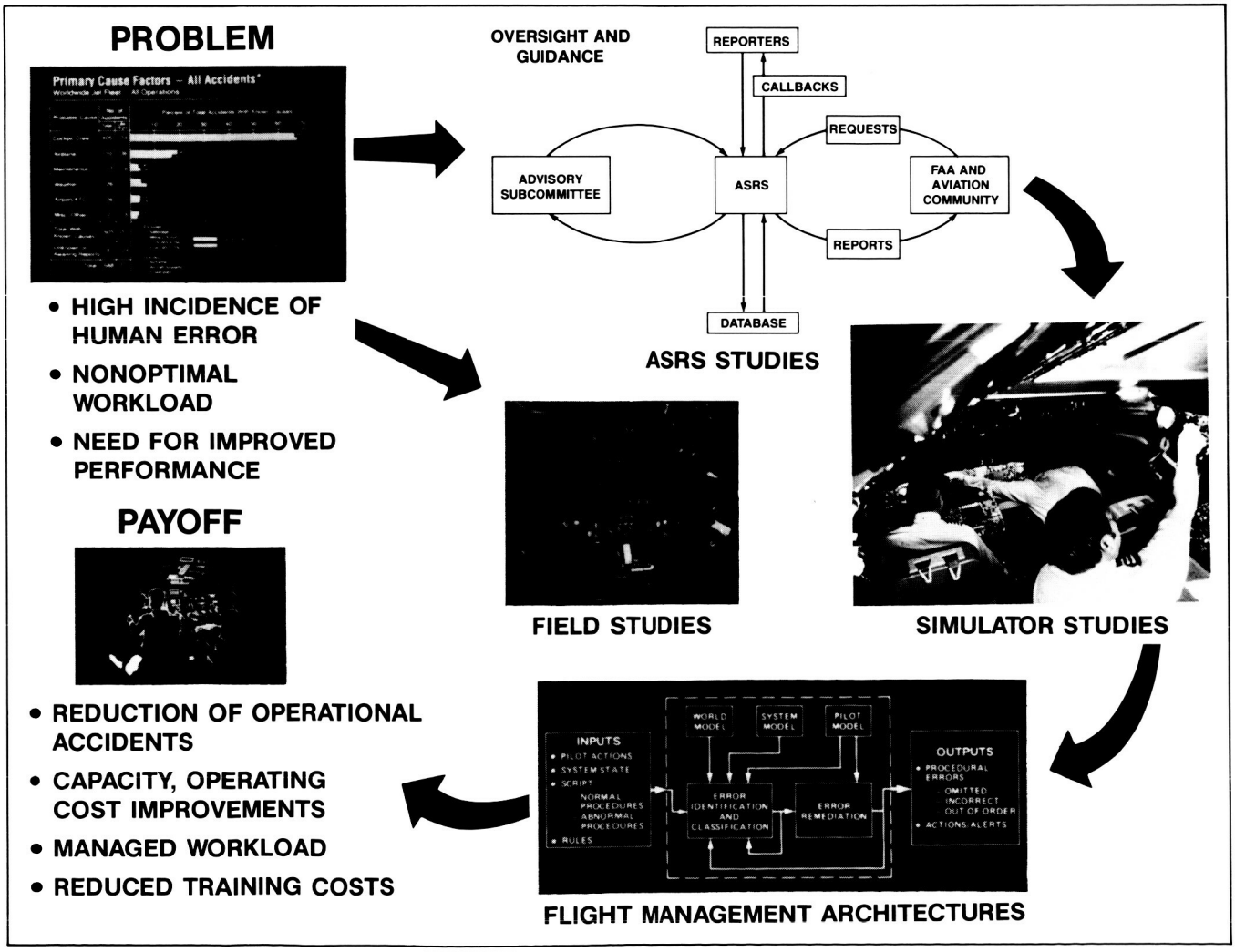
Accomplishments and applications of human orientation model

Goal-Directed, Error-Tolerant Flight Management

Human error continues to account for a preponderance of aircraft accidents that occur worldwide. In the U.S., increased traffic caused by deregulation, decreased fuel costs, and a nonexpanding U.S. airport inventory are combining to make more precise navigation and control a necessity. Finally, the growing use of automation in modern aircraft is altering the traditional role of the pilot and the distributions of physical and mental workload.

In an attempt to develop a rational understanding of how automation should be developed to maximize safety and performance in the modern cockpit, Ames Research Center has been engaged in a series of comprehensive studies of aircraft automation. Field studies of pilots' attitudes toward automation and their usage patterns are being augmented by structured callback studies using the Aviation Safety Reporting System incident database.

Previous studies suggested that it would be possible to develop computerized systems that could monitor for pilot errors, detect such errors, and either warn the pilot of their presence or autonomously take corrective action. A current focus for such systems is the detection of procedural errors. A system to detect such procedural errors within a sequence of crew actions is currently in development at Ames. At the same time, contracted studies of the applicability of artificial-intelligence techniques to crew error detection, procedural and decision-aiding, and system supervisory control are being conducted. The results of such studies will be a new generation of flight-management-system architectures, and a compre-



Flight management

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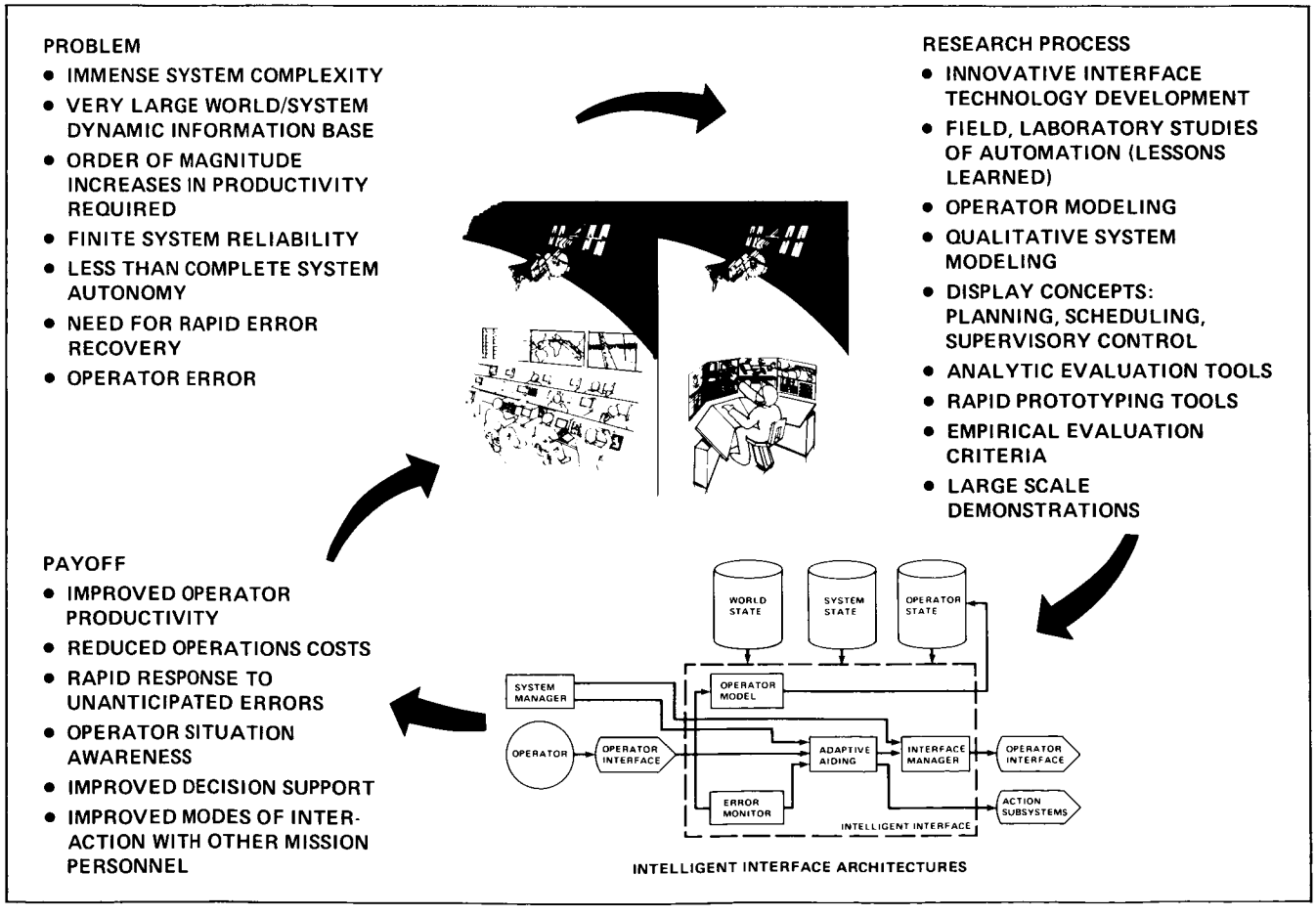
hensive set of guidelines for automation development that will ensure maximum compatibility with human pilot capabilities and limitations. The resulting new generation of flight-management systems will reduce the incidence of operational accidents and offer improvements in the areas of operating cost, aircrew workload, and training.

(E. Palmer, Ext. 6073)

Operator Interface to Autonomous Space Systems

Safety, cost, and performance considerations and a mandate from the U.S. Congress are spurring NASA's efforts to develop advanced automation for use in future space missions, both on the ground and in flight. Such efforts will never entirely eliminate humans, but will substantially alter their number and their roles. Those operators who remain in the system will, of necessity, deal with very complex systems; a large and dynamic world/system information base; and occasionally, systems which malfunction or fail. At such times, it will be essential that the human operator respond quickly and with minimum error.

A multifaceted program of research is required to make such automation a reality. The current research is focused on the operator interface. Lessons learned from previous attempts to automate complex systems (e.g., in aviation) are being compiled to guide the new developments. Formal models are being developed to understand the role of the human operator and to develop candidate tasks for automation. Qualitative system-modeling techniques are being developed to facilitate the explanation, by the automation to the human supervisor, of system malfunctions, failures, and the actions of the automated systems. Advanced display concepts and display rapid prototyping systems are being developed for planning and scheduling, as well as for supervisory



Operator Interface to Autonomous Space Systems

control. Analytic evaluation tools and empirical evaluation criteria are being developed for hybrid intelligence systems, all in preparation to support the large-scale Systems Autonomy Demonstration Project (SADP) activities scheduled for FY 88, FY 90, FY 93, and beyond, at various NASA field installations.

The result of these studies will be a comprehensive operator interface specification, design, and implementation for each of the planned SADP large-scale demonstrations projects.

(E. Palmer and R. Roske-Hofstrand,
Ext. 6073/5716)

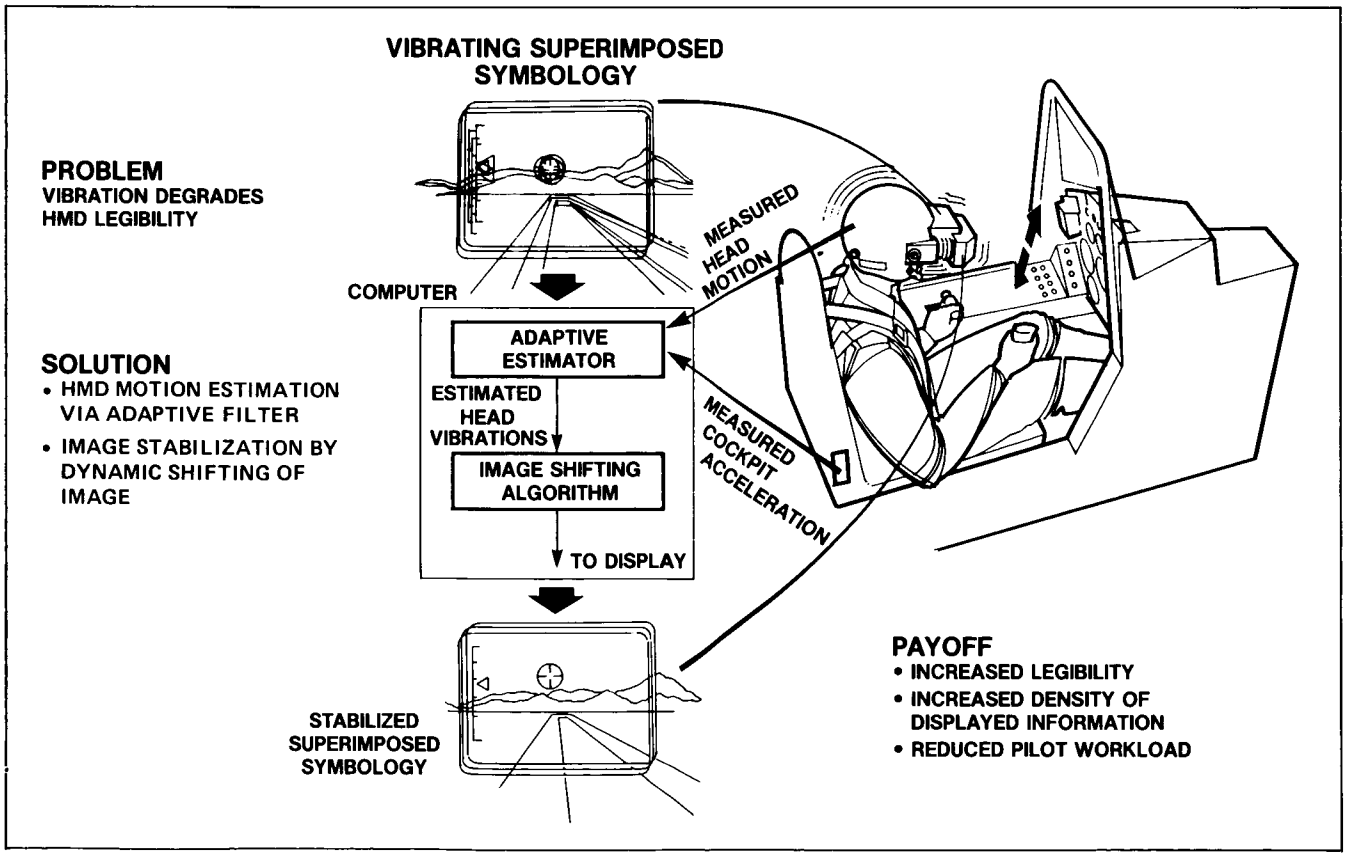
Reduction of Biodynamic Interference Effects While Using Helmet-Mounted Sights and Displays

Head-coupled devices such as helmet-mounted sights or helmet-mounted display (HMS/HMD) have been prompted by the growing need to reduce pilot workload caused by the increasing complexity of control tasks. However, under the frequently encountered conditions of vibrations, aiming accuracy as well as reading performance may be severely degraded because of two main factors: (1) involuntary head motion caused by vibrations; and (2) impairment of visual acuity resulting from the relative motion of the vibrating HMD and the essentially inertially stabilized line of sight.

This research is intended to develop a low-cost, efficient method for increasing the aiming accuracy of an HMS and for retaining visual acuity on an HMD.

A method that uses adaptive filtering techniques has been proposed for estimating voluntary and involuntary head movements. The method utilizes measurements of the head movements and of the vehicle accelerations. The estimated voluntary head movements are used to drive the pointing device, while the involuntary movements are used for the image-stabilization scheme.

Extensive computer simulations have been performed to examine the feasibility of the proposed method. It has been found that the proposed



Reduction of biodynamic effects in helmet-mounted displays

algorithm enables the estimation of both voluntary and involuntary head motion with an error smaller than 2 mrad, which is the accuracy of the measuring sensor. The adaptive filtering technique thus can restore the inherent aiming accuracy of the HMS and minimize the relative motion between the viewer's line of sight and the image displayed on the HMD.

(M. Velger and S. Ellis, Ext. 5150/6147)

Extravehicular Activity Simulations Test Apparatus

Ames Research Center has designed and is fabricating a small, neutral-buoyancy tank and chamber. This apparatus is intended to provide a low-operations-cost capability to evaluate suit and glove performance, and to support research in extravehicular activity (EVA) systems hardware design.

The EVA Simulations Test Apparatus includes two test areas. First, an enclosed chamber (9 ft in diam by 9 ft long) will function as a "suit box" whereby a rear-entry suit (such as the Ames AX-5 Hard Space Suit) is mounted to an opening in the chamber wall. The chamber is filled with water and a vacuum is drawn at the water surface. This arrangement allows for providing both a pressure differential across the suit structure and neutral buoyancy for the suit extremities.

Second, a tank (11 ft in diam by 9 ft deep) serves as a reservoir for the chamber water and also serves as a neutral-buoyancy test area for suit mobility and EVA workstation evaluation.

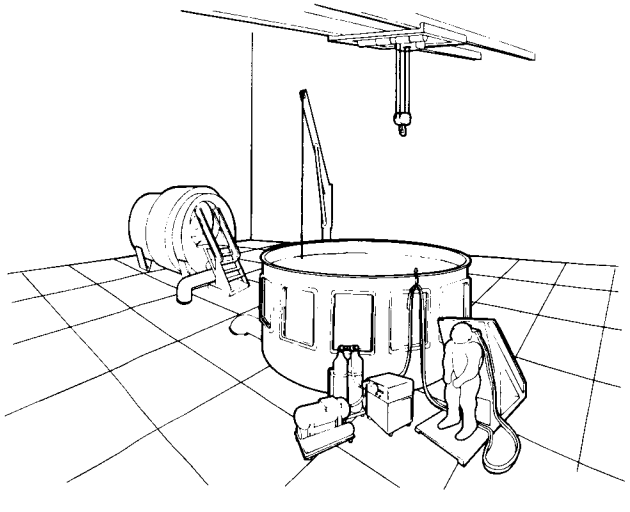
Tank installation began in August 1986 and chamber installation will start in January 1987.

(H. Vykukal, Ext. 5386)

Design, Development, and Evaluation of an Extravehicular Activity Prehensor

Ames Research Center and Stanford University have an ongoing cooperative agreement to develop human-powered "prehensors" or "end effectors" for extravehicular activity (EVA) suits. By replacing gloves, the prehensors promise to reduce astronaut hand fatigue and to extend the duration and safety of EVA missions.

Each prehensor consists of a shroud which forms a pressure enclosure around the astronaut's hand and a linkage system to transfer the motions and forces of the hand to mechanical digits connected to the shroud. Three different prehensors are currently under development, each representing an increasing degree of complexity: the prosthetic prehensor, the multigrasp prehensor, and the direct-link prehensor (DLP). A secondary task is the development and implementation of a Performance Assessment Work Station for evaluating prehensor designs.



OBJECTIVE

- SMALL NEUTRAL BUOYANCY TESTING APPARATUS FOR EVA SUIT AND GLOVE EVALUATION
- SUPPORTS TESTING PRIOR TO EXPENSIVE FULL WETF EVALUATIONS

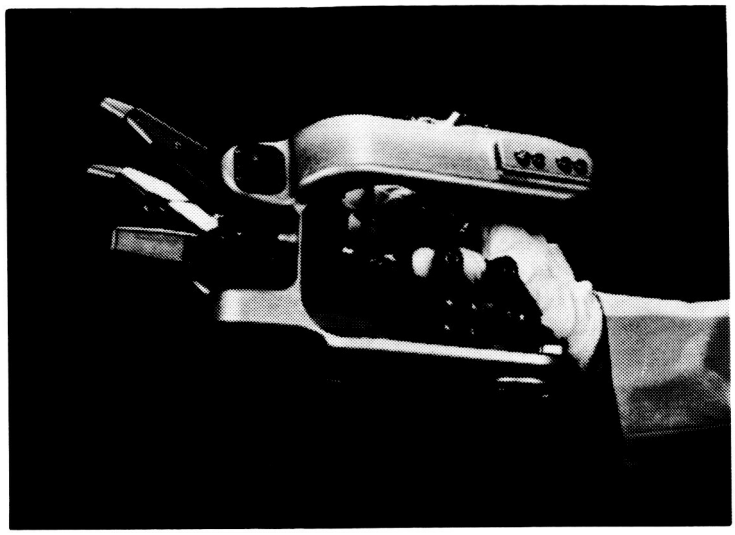
FEATURES

- EXPLOITS CHARACTERISTICS OF HARD SPACE SUIT WITH REAR ENTRY
- SUIT BOX CONCEPT ALLOWS FOR VARIATION IN WORKING PRESSURE DIFFERENTIALS
- RAPID EGRESS THROUGH SUIT HATCH MINIMIZES SAFETY PROBLEMS

SIGNIFICANCE

- FASTER, LOWER COST EVA SUIT/GLOVE CONCEPT EVALUATIONS
- FASTER DESIGN/EVALUATION CYCLES

Test apparatus



OBJECTIVE

- HIGH DEXTERITY PREHENSOR FAMILY FOR EVA
- DEVELOPMENT OF PERFORMANCE ASSESSMENT WORK STATION FOR END EFFECTOR EVALUATION

ACCOMPLISHMENT

- COOPERATIVE AGREEMENT WITH STANFORD UNIVERSITY
- DIRECT-LINK EVA PREHENSOR WITH TWO MOVABLE FINGERS, MOVABLE THUMB COMPLETED AUG., 1986
- WETF EVALUATIONS TO BEGIN IN FALL, 1986

PAYOFF

- REDUCED ASTRONAUT FATIGUE
- EXTENDED EVA MISSIONS
- IMPROVED EVA SAFETY

Human powered end effector

This design is restricted to single-degree-of-freedom hand motion and is intended to use off-the-shelf prosthetic hardware wherever feasible. The constraint on mobility is intended to establish criteria for mechanical simplicity, compactness, comfort, and ease of training by which more capable devices can be measured.

The multigrasp prehensor is configured as two anthropomorphic fingers opposing a thumb. It has two degrees of freedom. One corresponds to the curling of the fingers, which provides cylindrical and three-jaw chuck prehension; the other corresponds to the lateral movement of the fingers, which provides lateral and tip prehension. The thumb is passive, but may be prepositioned to extend the range of object sizes the hand will accommodate.

The DLP is a mechanically robust prehensor capable of basic grasping functions and some dexterity. This is achieved by an anthropomorphic configuration of two movable fingers opposed to a movable thumb. Each finger, as well as the thumb, is controlled independently with two degrees of freedom. The two fingers each have a third joint coupled to the medial joint which provides the curling motion necessary for cylindrical and spherical grasps. For the first-version DLP the motions of each finger and thumb are each constrained to a single corresponding plane. The control of the prehensor is very natural since the configuration of the mechanical digits parallels that of the astronaut's hand; in a sense, the mechanical fingers appear as a projection of the hand controlling them. The control motions/forces are transmitted to the mechanical fingers through a minimal set of mechanical linkages. Motion/force is transmitted to each mechanical digit from inside the pressure enclosure, or shroud, through two concentric shafts. The pressure differential is maintained by Teflon rotary seals to minimize frictional effects.

The first-version DLP, with shroud and suit interface, is scheduled to be completed in January 1987. Weightless Environment Test Facility evaluation will begin in the spring of 1987. Completion of the prosthetic prehensor is scheduled for April 1987 and completion of the multigrasp EVA prehensor is scheduled for April 1987.

(H. Vykukal, Ext. 5386)

Advanced Hard-Glove Development

Ames Research Center is developing a high-pressure hard-glove concept to develop and evaluate glove technology which uses miniature metal bellows in the fingers, thumb, and wrist joints. Soft structures are located in the anterior portions of the finger and thumb tips to allow for tactile feedback. The operational design pressure is 10 psig.

A functional prototype has been fabricated and evaluated for finger/thumb mobility at 10 psig. Finger mobility is excellent; however, the thumb mobility range of motion is not adequate for large-object grasp. Incorporation of a first metacarpal joint would enhance overall glove performance.

One pair of gloves and five metal bellows wrist joints were completed in July 1986. A pair of upgraded gloves incorporating the improved functional features will be completed in August 1987.

(H. Vykukal, Ext. 5386)

OBJECTIVE

- HIGH PRESSURE, HIGH MOBILITY GLOVE
- ADEQUATE TACTILITY FOR MANUAL EVA TASKS

ACCOMPLISHMENT

- FUNCTIONAL PROTOTYPE FABRICATION COMPLETE
- COMPLETE GLOVE WITH 5 METAL BELLOW WRIST JOINTS COMPLETE JULY, 1986
- FINGER/THUMB MOBILITY EVALUATED AT 10 psig
- IMPROVED DESIGNS UNDER DEVELOPMENT

SIGNIFICANCE

- HIGH PRESSURE GLOVE PACING TECHNOLOGY ITEM FOR COMPLETE HIGH PRESSURE SUIT

Advanced hard-glove development

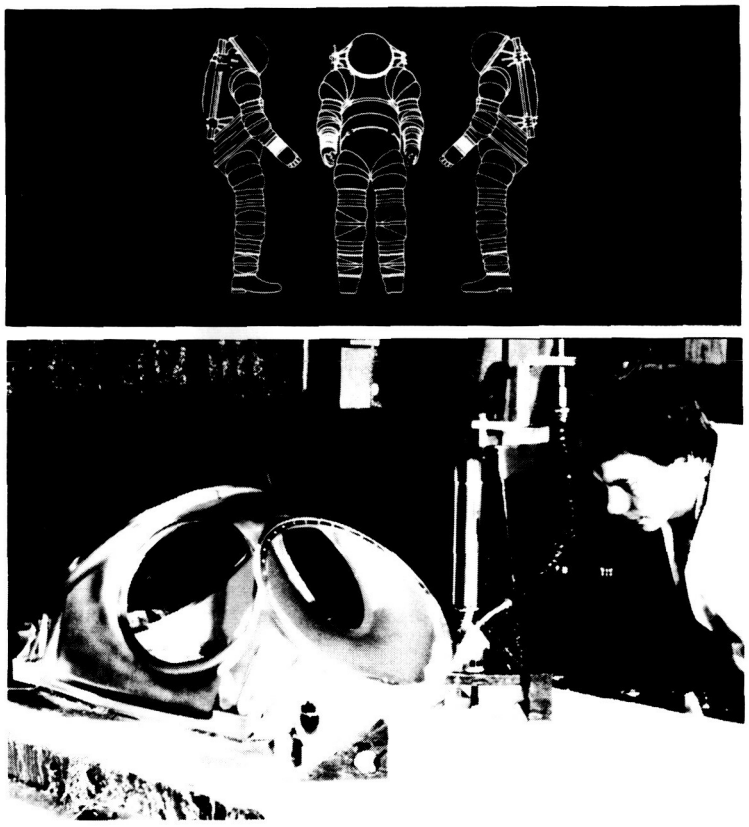
Ames AX-5 Hard-Space-Suit Demonstrator

Ames Research Center has an ongoing development program to address extravehicular activity (EVA) suit technology issues for Space Station to develop a suit which requires no prebreathing (operational internal pressure up to 1 atm); provide for improved mobility and hazard protection (radiation, debris, thermal, mechanical); incorporate a quick-change sizing capability; and which is designed for minimal maintenance, manufacturing, and operations costs.

The Ames AX-5 hard-space-suit demonstrator structure is fabricated of aluminum, featuring a low-torque, low-leakage, multiple-bearing-joint system. For ease of donning/doffing, a rear-entry hatch system is employed. Thermal coatings (which will be applied to the outer surface) have been tested and evaluated for thermal protection, eliminating the need for a bulky outer thermal meteoroid-protection garment. Structural options allow for a double-hulled structure configuration for improved debris and radiation protection.

Two suits are being fabricated with an expected completion of suit 1 in August 1986 and suit 2 in February 1987. Weightless Environment Test Facility evaluation will begin in the spring of 1987.

(H. Vykukal, Ext. 5386)



ACCOMPLISHMENT

- TWO SUITS FABRICATED
- PRELIMINARY JOINT, SEAL LEAK TESTING ACCOMPLISHED
- WETF QUALIFIED

SIGNIFICANCE

- ONE ATMOSPHERE WORKING PRESSURES
- IMPROVED HAZARD PROTECTION
- ON-ORBIT SIZING
- REDUCED MAINTENANCE
- MINIMIZED PARTS INVENTORY
- STANDARD AEROSPACE MANUFACTURING TECHNIQUES
- MEETS OPERATIONAL REQUIREMENTS FOR SPACE STATION
- EVOLUTIONARY TECHNOLOGY

Ames AX-5 hard-space suit

Machine Vision for Aircraft Guidance and Terrain Avoidance

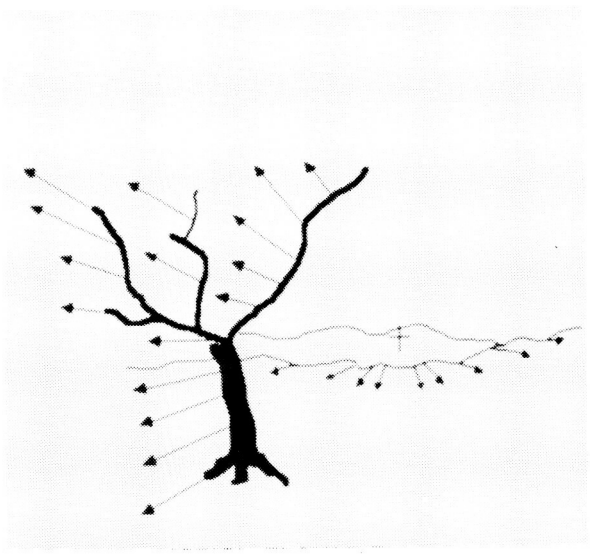
Machine-vision systems are being examined to assist the helicopter pilot to accomplish demanding nap-of-the-Earth (NOE) and other missions where workload or other factors might preclude the use of a single pilot. Since helicopter accidents are frequently caused by impact of the aircraft with wires or other obstructions, machine vision offers a potential solution to a major safety problem associated with helicopter operation.

The Ames Research Center machine-vision effort uses several years of development of computational codes that emulate the function of the human visual-motion-detection system. The existing codes, which extract optical flow at varying scales from sequences of sampled dynamic images, are being modified to support their use as guidance and control algorithms. Other studies are directed toward the development of velocity and range mapping algorithms and the analysis of the image characteristics of typical NOE vision sensors.

(A. Watson, Ext. 5419)

Model-Based Image Processing

The objective of this program is to apply models of human vision in the design of image-processing algorithms and tools. These tools will be used in image coding, compression, transmission enhancement, and display. Applications are in image-management systems, machine vision, telerobotic displays, teleconferencing systems, and advanced image displays.



MOTION FLOW FIELD

GOALS

- OBSTACLE AVOIDANCE
- ASSISTED/AUTOMATED GUIDANCE
- ANOMALY DETECTION

STRATEGY

- DEVELOPMENT OF VISION ALGORITHMS FOR VELOCITY ESTIMATION, OPTIC FLOW, AND RANGE ESTIMATION
- ANALYSIS OF NOE IMAGERY
- SIMULATION OF VISION ALGORITHMS FOR NOE

Machine vision for helicopter pilots

A CORTEX Transform has been developed that maps an image into a set of coefficients corresponding closely to those used by the visual brain. This code has been used to compress digital images. Preliminary results suggest the method may exceed compression ratios available with other methods. In this work we have also developed the first robust objective methods for evaluating the perceptual fidelity of a compressed image. This will allow us to compare our techniques with others.

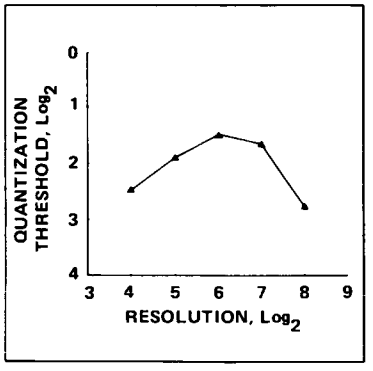
Under a consortium agreement, the University of California at Irvine is exploring the Constant Volume Operator method of image processing. This radically different method, also based on properties of human vision, has the remarkable property of matching its resolution to the quantum noise in the image over many orders of magnitude of image brightness.

Ideal methods of shrinking and expanding an image have been developed, and these have led to an ideal pyramid representation of an image. This scheme partitions an image into subsampled, one-octave bands of spatial frequency. This transform is useful in progressive image transmission, image coding, and variable resulting machine vision.

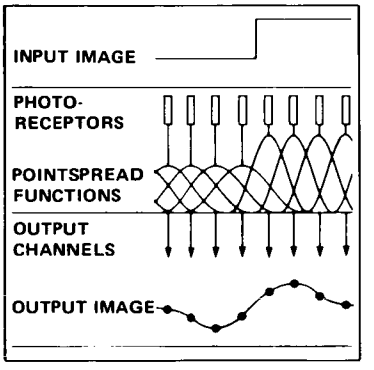
As a guide to how images may be effectively displayed to an operator, we have conducted studies of human image-recognition. The results indicate recognition to be highly dependent upon resolution, but independent of size. These results have important ramifications for image transmission and display; for example, how many bits need be transmitted to reconstruct a recognizable display, and how many images may be placed on a single screen.

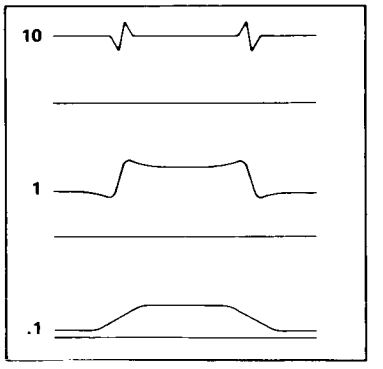
(A. Watson and A. Ahumada, Ext. 5419/6257)

CORTEX TRANSFORM



CONSTANT VOLUME OPERATOR



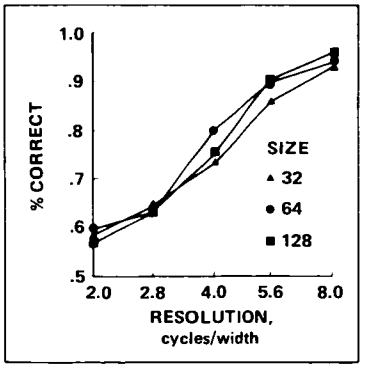


SPOT RESPONSE TO POISSON NOISY INPUT AT THREE BRIGHTNESSES

HUMAN IMAGE RECOGNITION

OBJECTIVE ESTIMATES OF SIZE AND RESOLUTION REQUIREMENTS FOR RECOGNITION OF IMAGES (FACES)

RESULT: PERFORMANCE DEPENDENT ON RESOLUTION, NOT SIZE



PAYOFFS

- EFFICIENT METHODS FOR IMAGE CODING, TRANSMISSION, DISPLAY
- NEW GENERATION OF INFORMATION DISPLAY
- DESIGN TOOLS FOR ADVANCED DISPLAYS
- MACHINE VISION

Model-based image processing tools

The Use of Color in Cockpit Displays

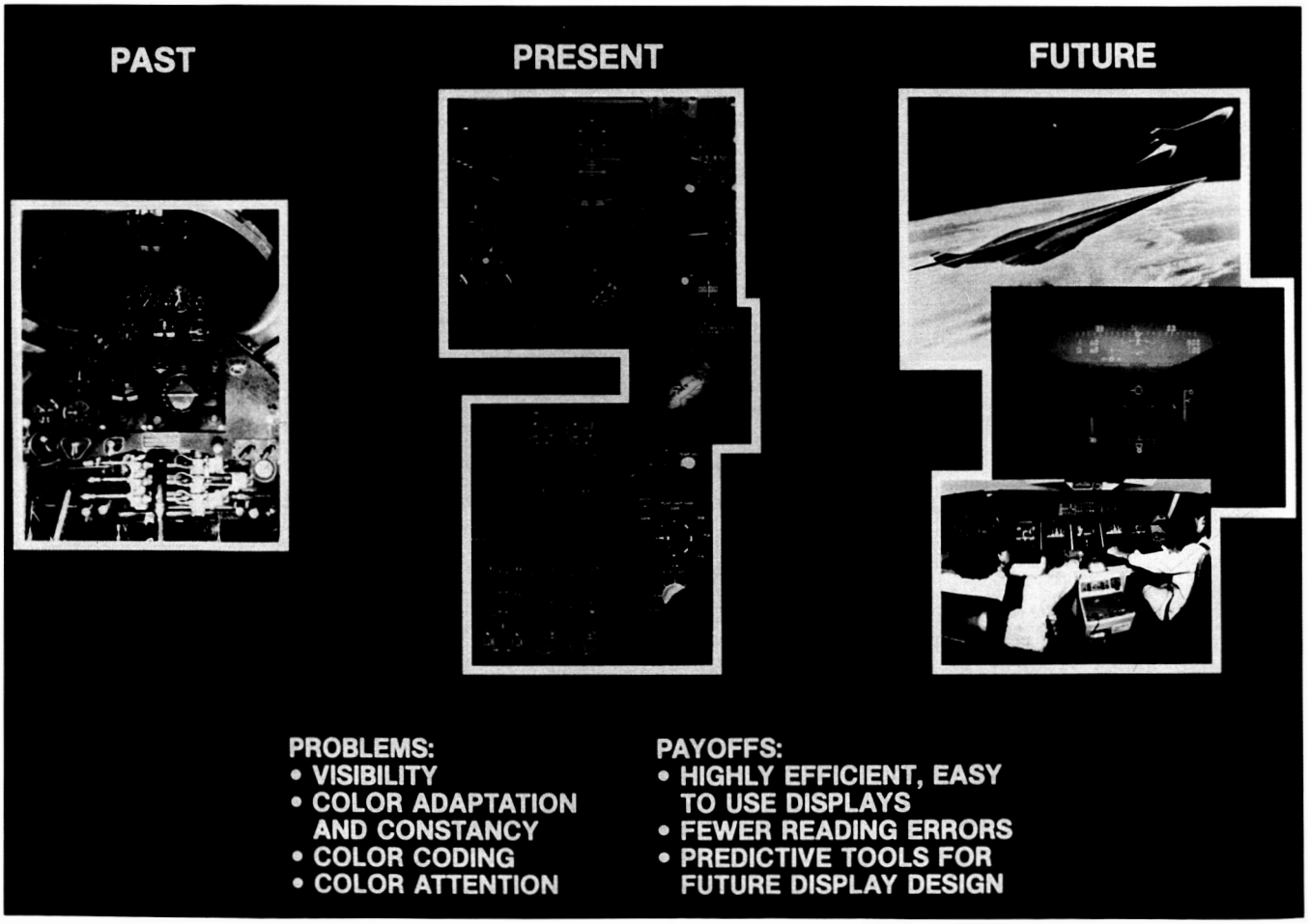
The aviation industry is transitioning from electromechanical display technology to color cathode-ray tube, flat panel, and projections displays. Although color provides a rich dimension for information transfer in the glass cockpit, to date the basis on which display design color choices are made has received inadequate attention.

In February 1986, Ames Research Center brought together a panel of experts on color vision for a 2-day meeting to consider the use of color in cockpit display systems. Following briefings by aircraft industry experts, the participants at the workshop identified four major problem areas: (1) the effects of high ambient illumination on display visibility, (2) chromatic adaptation and color constancy, (3) learned color associations, and (4) color as an aid for focusing attention.

High ambient light levels can result in veiling glare, momentary blindness, and loss of display contrast. Changes in the observer's adaptation state are especially troublesome in displays using color. Chromatic adaptation is known to alter the color appearance of lights and could dramatically change the appearance of a display. Adaptation is a dynamic process and therefore these color-appearance shifts can occur during periods of rapid illumination changes such as maneuvering in bright sunlight. Some colors have greater stability than others and are therefore preferred in display design. Although these phenomena are present in all displays, old or new, the use of color requires finding those colors least susceptible to these effects.

A third problem with color displays is the traditional use of color to code meaning in our culture. For example, red is used to signal danger, yellow caution, etc. These are overlearned associations; deviations from population stereotypes in display design can lead to tendencies toward errors or additional training requirements.

Finally, recent research into the psychology of attention has shown that color elements in a display can capture the attention of the observer.



Color in avionics displays

Pop-up which is due to unique color coding can be exploited to capture the pilot's attention during critical moments of information display and transfer.

(A. Watson and J. Larimer, Ext. 5719/5150)

Space Shuttle Simulation 1986

The Space Shuttle program office conducted experiments using the vertical motion simulator (VMS) to study the nose-wheel steering system and braking. The VMS is ideal for studies of this type because of its unique motion capability, a visual system that can be customized to the needs of the program, and its flexible engineering configuration which allows many options to be installed and evaluated in a short period of time.

The simulation conducted in March/April 1986 concentrated on evaluating various nose-wheel steering-control systems. Although evaluation of autobraking had been considered a high priority, it was quickly realized that improvements to the landing gear in the form of new tire data resulted in different performance of nose-wheel steering. For this reason, the focus of the VMS testing moved to an in-depth study of various nose-wheel steering-control systems.

Initially, an engineering evaluation session, supported by 4 astronauts and 11 engineers, verified the nose-wheel control-law configurations, the additions to the head-up display symbology, and the performance of cockpit controls and displays.

Later, approximately 20 astronauts and 4 engineers flew the simulation to conduct engineering evaluations and rollout training. During the evaluation and training period, 1,600 motion flights were made. Since each simulator flight starts just prior to touchdown, many astronauts obtain valuable experience on one of the most demanding tasks in any Shuttle mission. The ability to simulate crosswinds and blown tires prepares them for almost any eventuality.

The results from this simulation have shown the need for even more tire data to confirm and verify the simulation performance. Tests are being run at Langley Research Center to acquire these data by late 1986 with plans for evaluation on the VMS in early 1987.

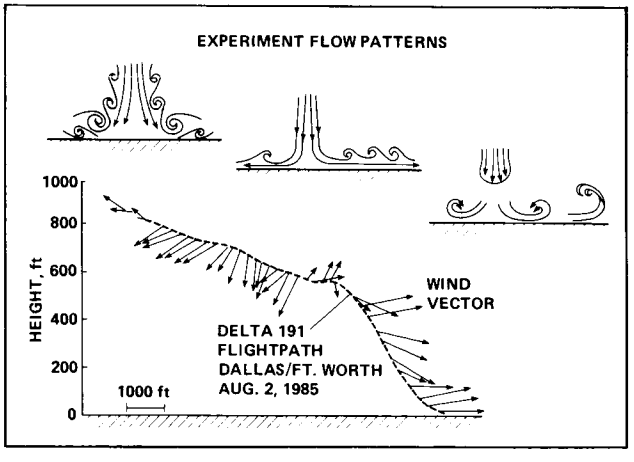
(D. Astill, Ext. 6171)

Investigation of Low-Level Microbursts

The advanced flight-data-analysis methods developed at Ames Research Center are providing new insight into the microburst phenomenon. As part of the National Transportation Safety Board performance group, researchers from Ames have applied these methods in the analysis of the data from the Delta L-1011 accident on August 2, 1985, at the Dallas/Fort Worth Airport. The measurements from the Digital Flight Data Recorder and the Air Traffic Control (ATC) radar records have been used to determine the wind vector along the flightpath. In this analysis the accelerations measured aboard the aircraft were integrated to determine a time history of the flightpath matching the ATC radar data. The wind-velocity vector was determined as the difference between the vehicle inertial velocity and its velocity with respect to the air mass.

The general pattern of the results indicates that the aircraft encountered a strong downflow, followed by a strong outflow, accompanied by large and rapid changes in the vertical wind. Although rain was present in the downburst, the analysis showed no evidence of performance loss.

The rapid changes in the vertical component of the wind near the ground detected from these data are attributed to vortex-induced turbulence.



Microburst flow pattern from flight and experiment

The Ames measurement of winds from the L-1011 accident is now being used in flight simulators by the aircraft industry and airlines to better understand the control problems in this type of severe encounter. These wind measurements also will be used as a standard of comparison in ongoing experiments and modeling of microbursts involving vortex rings.

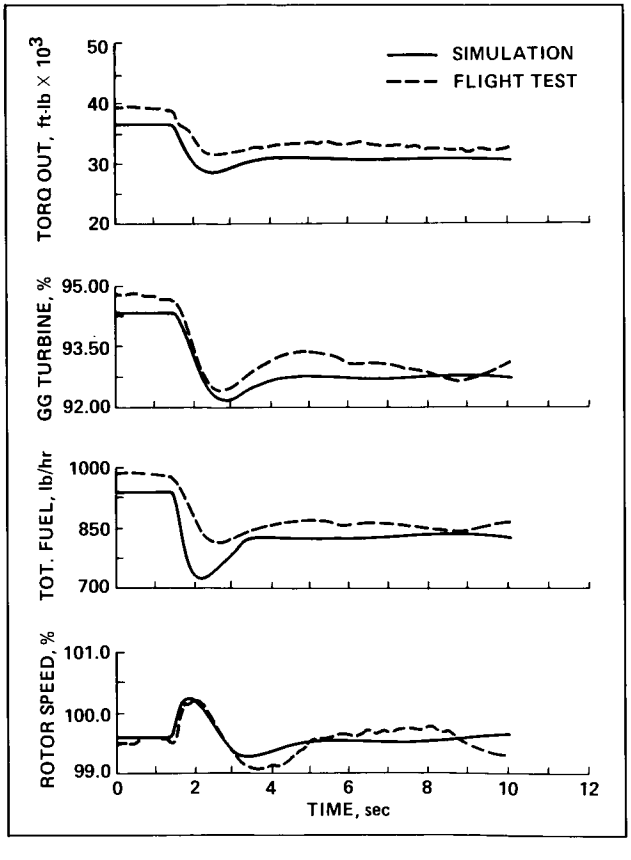
(R. Bach and R. Wingrove, Ext. 5429)

A High-Fidelity Real-Time Digital Simulation of a Small Turboshaft Engine

Recent studies suggest that a significant enhancement of helicopter handling qualities may be achieved by improving rotor speed governing. As part of the ongoing vertical motion simulator (VMS) effort to explore the improvements attainable, and to investigate new methods of propulsion-system control, a real-time digital simulation of a GE T700 engine (including hydromechanical and electrical fuel-control systems) was developed. The simulation has a level of sophistication compatible with helicopter math models such as the GEN HEL UH-60A Black Hawk. Rather than using partial derivative representations, the major engine components and the dynamics of several internal engine states are modeled based on physical laws relating to transfer of energy and mass flow. This allows great flexibility and an accurate representation of engine performance and dynamics over a full operating range.

A hybrid engine simulation developed at Lewis Research Center was used as a basis. The engine manufacturer was consulted to incorporate the additional details necessary to achieve a high-fidelity simulation. The program was interfaced with the GEN HEL UH-60A simulation, and additional details were added to the helicopter mathematical model as necessary. These included the addition of a gearbox and engine overrunning clutches, and modeling of required tail-rotor power. The simulation was validated using USAAEFA flight-test data. It has been used by Sikorsky in their study to develop integrated flight/propulsion control concepts, a program sponsored by Lewis.

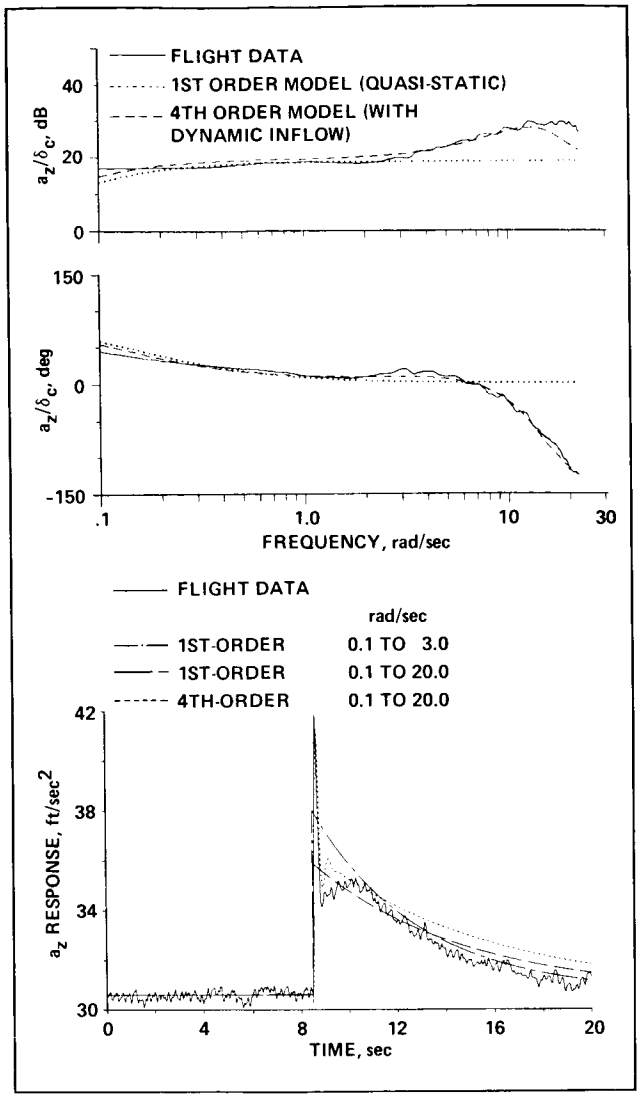
(M. Ballin, Ext. 6115)



Typical engine and rotor system response (UH-60A in hover, 1 in. collective stick reduction in 0.2 sec)

Influence of Dynamic Inflow on Rotorcraft Flight Dynamics

With the advent of superaugmented, high-gain flight-control system for military rotorcraft to meet the requirements of demanding missions such as nap-of-the-Earth flight or aerial combat, it becomes increasingly important that high-order dynamics be adequately modeled in the design process. This is in contrast to past practice when only the lower-frequency, quasi-static, rigid-body flight dynamics were used in the design of low-gain flight-control systems. Recent flight investigations with the variable-stability CH-47B research helicopter at Ames Research Center have shown that high-order elements such as rotor dynamics, dynamics of sensor filters, servo actuators, and data-processing delays of the airborne computer must be adequately modeled for the design of high-gain flight-control systems.



Transfer function models fit to flight-extracted Bode plots CH-47B

Inclusion of air-mass dynamics may also prove to be important in the design of a high-gain flight-control system for rotorcraft because the frequencies of the inflow dynamic modes are the same order of magnitude as those of the rotor-blade flapping and lead-lag modes. A study was therefore conducted in FY 86 to investigate the effects of dynamic inflow on rotor-blade flapping and vertical motion of the helicopter. Linearized versions of two dynamic inflow models (one developed by Carpenter and Fridovich and the other by Pitt and Peters) were incorporated in simplified rotor-body models and were compared for variations in thrust coefficient and the blade Lock number. In addition, a comparison was made between the results of the linear analysis, and the transient and frequency responses measured in flight on the CH-47B variable-stability helicopter. Results indicate that the correlations are good. The linear analysis also shows that dynamic inflow plays a key role in destabilizing the flapping mode. The destabilized flapping mode, along with the inflow mode, results in a large initial overshoot in the vertical acceleration response to an abrupt input in the collective pitch. This overshoot becomes more pronounced as either the thrust coefficient or the blade Lock number is reduced. Compared with Carpenter's inflow model, Pitt's model tends to produce more oscillatory responses because of the less stable flapping mode predicted by it. It is planned to extend the research in FY 87 to include examinations of the effects of dynamic inflow on the pitch and roll dynamics of the helicopter.

(R. Chen, Ext. 5008)

Dual-Lift Control

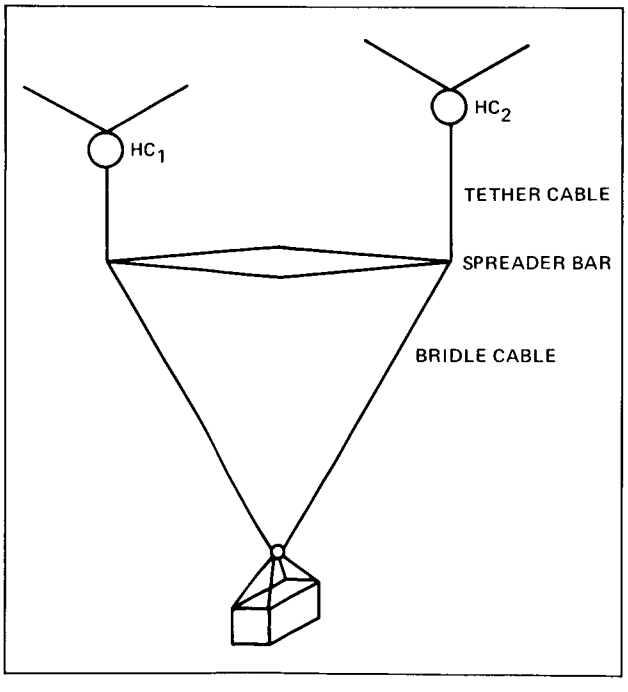
Some payloads are too large to be moved by a single helicopter. Consequently, dual helicopters may be used to complete the mission. The system to be controlled consists of two helicopters carrying a load suspended on cables separated by a spreader bar. Such a system has been considered periodically since the initial success of operations using loads slung from single helicopters, but has yet to be developed. A significant obstacle has been the complexity and workload of the system coordination and control task. Current digital flight-control systems and new methodology developed by Ames Research Center for the design of automatic flight-control laws for nonlinear systems offer a basis for the control of the dual-lift system.

The steady-state characteristics of the dual-lift configuration at any static equilibrium or maneuvering flight condition have been studied, and results have been obtained for the suspension-system geometry and forces, and the thrust-vector requirements for any helicopter pair, load-sharing ratio, and formation angle relative to the ground track. It is found that the tether angles can be selected for minimum thrust, the spreader-bar tilt controls load sharing, and the variation in system geometry with maneuvering depends strongly on the selected formation angle. These results provide a basis for coordinating the helicopters with automatic or manual control along any reference trajectory.

A mathematical model of the system dynamics is required for simulation and control law design. Kane's Lagrange-D'Alembert formulation of system dynamics has been applied to obtain a general form of the simulation equations applicable to all slung-load systems. Application of this result to the dial-lift system is in progress using the MACSYMA symbol-manipulation software. The object is to obtain a formulation which accommodates the enormous number of dynamic terms in a practical simulation algorithm and analytical model. In addition, an aerodynamic model of the MILVAN is being compiled as a typical, difficult-to-stabilize slung load. A comprehensive model of the static aerodynamics has been obtained by extrapolating the available wind tunnel data based on the symmetry of the MILVAN.

Linear models and system analysis of dual lift have been studied under a grant to Princeton University. Studies of two-dimensional motion near hover have been completed, reported, and implemented in a commercial simulation study. A linearized model for three-dimensional hover motion has been obtained by applying Lagrange's equations using MACSYMA, and analysis is in progress.

(L. Cicolani and G. Kanning, Ext. 5446/6037)



Dual-lift system

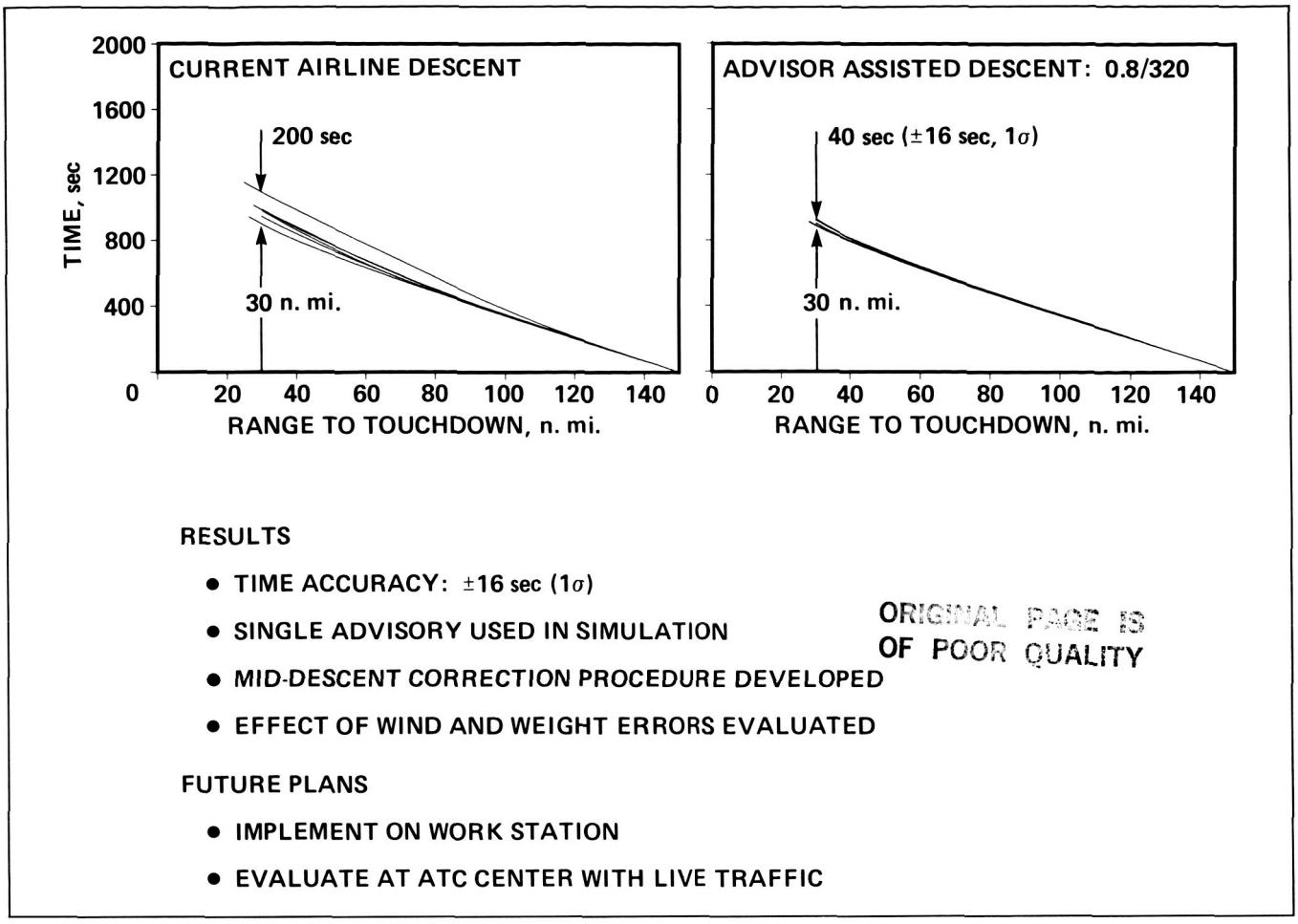
Four-Dimensional Descent-Advisor Expert

A ground-based four-dimensional (4-D) descent-advisor concept is being developed and tested in an effort to automate terminal-area traffic management of conventionally equipped aircraft. The objective of this work is to increase airport landing rates, improve fuel efficiency, and reduce delays through greater automation of the air-traffic-control (ATC) process.

The 4-D descent-advisory algorithm is designed to interface with an ATC host computer. The algorithm includes accurate models of airline descent procedures, aircraft performance, and atmospheric data. The algorithm is interfaced with the air-traffic scheduler and generates 4-D trajectories for unequipped aircraft entering the terminal area. The trajectory is output to the air-traffic controller in the form of a speed advisory and a top-of-descent point. The controller then issues the advisory to the pilot of the unequipped aircraft who tracks the speed profile given in the advisory so as to arrive at the scheduled time.

A piloted simulation was conducted on the Ames Research Center's 727 full mission simulator to determine the accuracy in which airline pilots could fly several representative speed profiles under various wind conditions. The descents flown with the advisories showed a striking reduction in descent time variability, as well as in fuel consumption, when compared to those flown without them. The time variability of the descents without the advisories was 200 sec at 30 n. mi. from touchdown. This is unacceptable for future time-based ATC systems. With the advisories, the time variability was reduced to less than 40 sec at that point which meets time/accuracy requirements. In addition, a mid-descent correction procedure was developed and the effects of errors in the estimation of wind and aircraft weight were studied. The high time/accuracy demonstrated in the simulation removes a critical obstacle toward implementing a time-based traffic-management system in the near future. On the basis of these favorable results, NASA and the FAA plan to evaluate the descent-advisor concept under live traffic conditions at an enroute ATC facility.

(T. Davis and H. Erzberger, Ext. 5452/5425)



Four-dimensional descent advisor piloted simulation

Helicopter Engine-Out Studies

The helicopter engine-out study seeks to determine whether significant autorotation safety improvements are possible because of control technique or aircraft equipment changes. A second objective of the study is to determine the simulator elements necessary for autorotation simulation for research and training.

A significant portion of all helicopter accidents (including training) involve an autorotation. The maneuver requires pilot skill, judgment, and proficiency. Military and civilian operators want to conduct such training in a safe, ground-based environment. Information gained from this research study will assist the FAA's development of helicopter training simulator requirements.

Two autorotation simulation experiments have been conducted on the Ames Research Center's vertical motion simulator (VMS). The first experiment, conducted in January 1984, investigated the influence of rotor and control-system variations on autorotation landing success. The experiment successfully identified those factors influencing the definition of the height-velocity restriction curve.

Simulation studies for helicopter engine-out

A second autorotation experiment was conducted on the VMS in June-July 1985. Systematic variation-of-motion cues showed changes in collective control technique during the landing flare with reduced motion. Visual scene variations showed the importance of easily recognized scaling objects when using computer-generated visual image displays. Height perception just prior to touchdown remained difficult with the computer-generated imagery available on the VMS. Continued development of a helicopter sound model was important to the autorotation task, which concentrates pilot attention external to the cockpit. A head-up display of aircraft situation, including rotor rpm, was usable during the approach, but could be distracting during the landing flare.

Future work includes another VMS entry in early 1987 and initial application of optimal control techniques to autorotation flight-dynamics analysis, based on joint work with Stanford University. The goal is the application of such techniques to the design of an autorotation flight director.

(W. Decker, Ext. 5362)

Helicopter Satellite-Based Guidance

A differential global positioning system (DGPS) developed for NASA Ames Research Center is being used to assess the capability of civil helicopters to perform terminal approaches into remote areas. A DGPS is a particularly attractive alternative mechanization of GPS which provides significant improvements in performance when compared to conventional GPS systems. This additional performance may prove sufficient to support helicopter precision approach and landing operations into areas not currently served by ground-based guidance aids. Offshore explorations, operations into remote and mountainous terrain, and inter/intracity emergency medical rescue are examples of helicopter missions that can be supported by DGPS.

The DGPS concept requires both an airborne and a ground-based GPS system. The airborne research system was developed at Ames and is installed in a NASA helicopter. The gound-based component was developed under contract by Ohio University, installed in a mobile van complete with a telemetry data link, and delivered to Ames in the fall of 1985. Static validation of the ground and airborne components was completed in early 1986.

The current investigations are concentrated on evaluating the performance of the airborne and ground-based components in a real-time dynamic environment. Research test activities are conducted at the Crows Landing NAS Facility where precision radar and laser trackers provide position "truth" for navigation-performance evaluation. In these tests the DGPS ground system transmits the differential correction information to the aircraft where it is incorporated into the airborne navigation solution to provide more accurate position information. Guidance errors from the on-board computer-generated glide path are displayed to the pilot and flown as if they were an ILS signal.

Preliminary results indicate that lateral navigation performance is adequate to support precision approach, but that vertical-axis performance, although considerably improved, requires further enhancement. Several alternative techniques are being investigated which should improve the vertical-axis performance of differential GPS. Initially, vertical accelerometer and barometric altimeter aiding are being evaluated. These and other techniques promise significant performance increases.

In-flight evaluation of the concept was concluded in the fall of 1986. Longer-term plans include the development of integrity monitoring tools for incorporation in the ground reference system.

(F. Edwards, Ext. 5437)

Airborne and ground components of the differential global positioning system

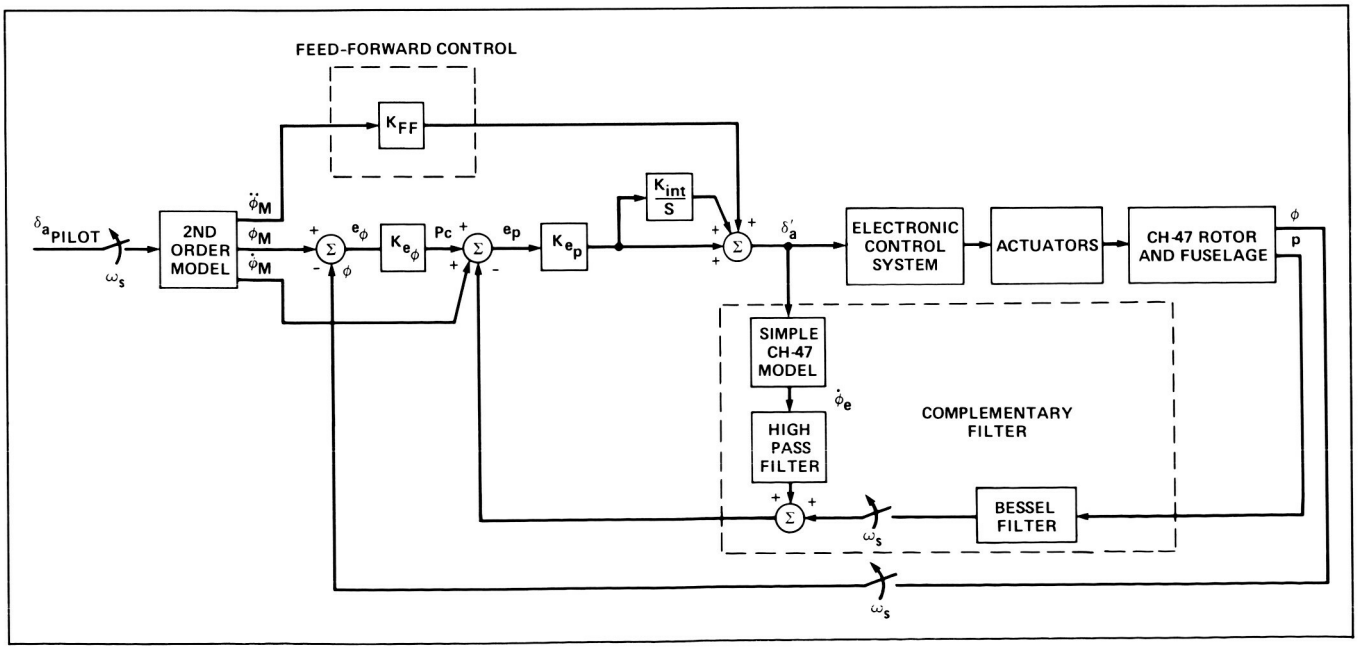
Flight Investigation of a Multivariable Model-Following Control System for Rotorcraft

A high-bandwidth, multivariable, explicit model-following control system for advanced rotorcraft has been developed and evaluated on the Ames Research Center CH-47B fly-by-wire helicopter. This control system has expanded the in-flight simulation capabilities of the CH-47 to support research efforts directed at the next generation of superaugmented helicopters. A detailed analytical model of the augmented CH-47B has also been developed to support the flight tests. An analysis using this theoretical model exposed the fundamental limitations caused by the basic vehicle characteristics and original control-system implementation that had affected the performance of the model-following control system. Two improvements, a feed-forward control law and a complementary filter, were made to the nominal control-system design to compensate for large time delays created by the higher-order dynamics of the aircraft and its control system. With these improvements, high-bandwidth control and excellent model-following performance were achieved.

This new control system will be used to study the effects of different response characteristics on helicopter handling qualities for a variety of tasks.

(K. Hilbert, Ext. 5272)

CH-47B variable-stability helicopter



Revised lateral model-following control system

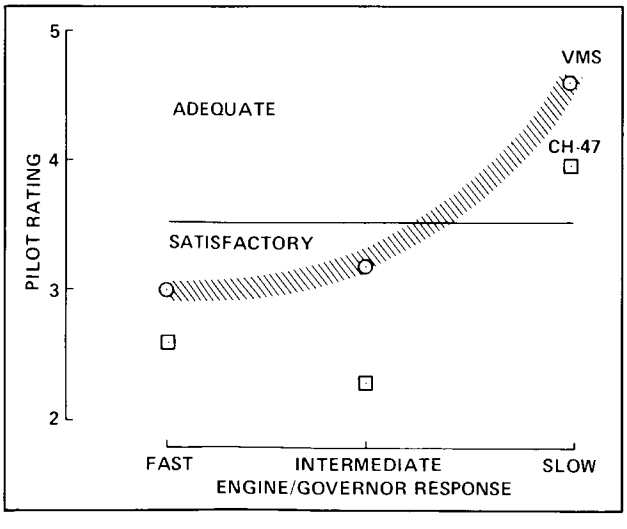
Flight Evaluation of Height-Response Characteristics for the Hover Bob-Up Task

A flight experiment was conducted to assess the validity of the results obtained in previous ground-based and in-flight simulations in the context of a precision bob-up task, and to provide additional flight data for inclusion in revisions to specifications for helicopter handling qualities.

The CH-47B variable-stability helicopter was used to evaluate a range of height-response configurations while performing a precision hover bob-up task. Height-response characteristics were implemented using explicit model-following techniques, and the resulting CH-47B dynamics were validated using time-domain and frequency-domain data-analysis methods. The tests complemented the previous investigations by providing detailed pilot comments and ratings, and performance and control-utilization data that relate exclusively to the hover bob-up task.

The research has provided the baseline from which to extend the investigation of height-control requirements for rotorcraft into other areas. Vertical control power, the influence of engine governor system dynamics, and integrated flight- and propulsion-system controls, and the influence of degraded visual cue environments on flight-control system features for the vertical axis are among those areas being considered for future research.

(W. Hindson and J. Lebacqz, Ext. 5008/5009)



Comparison with previous results for hover bob-up tasks

Crew Station Research and Development Facility

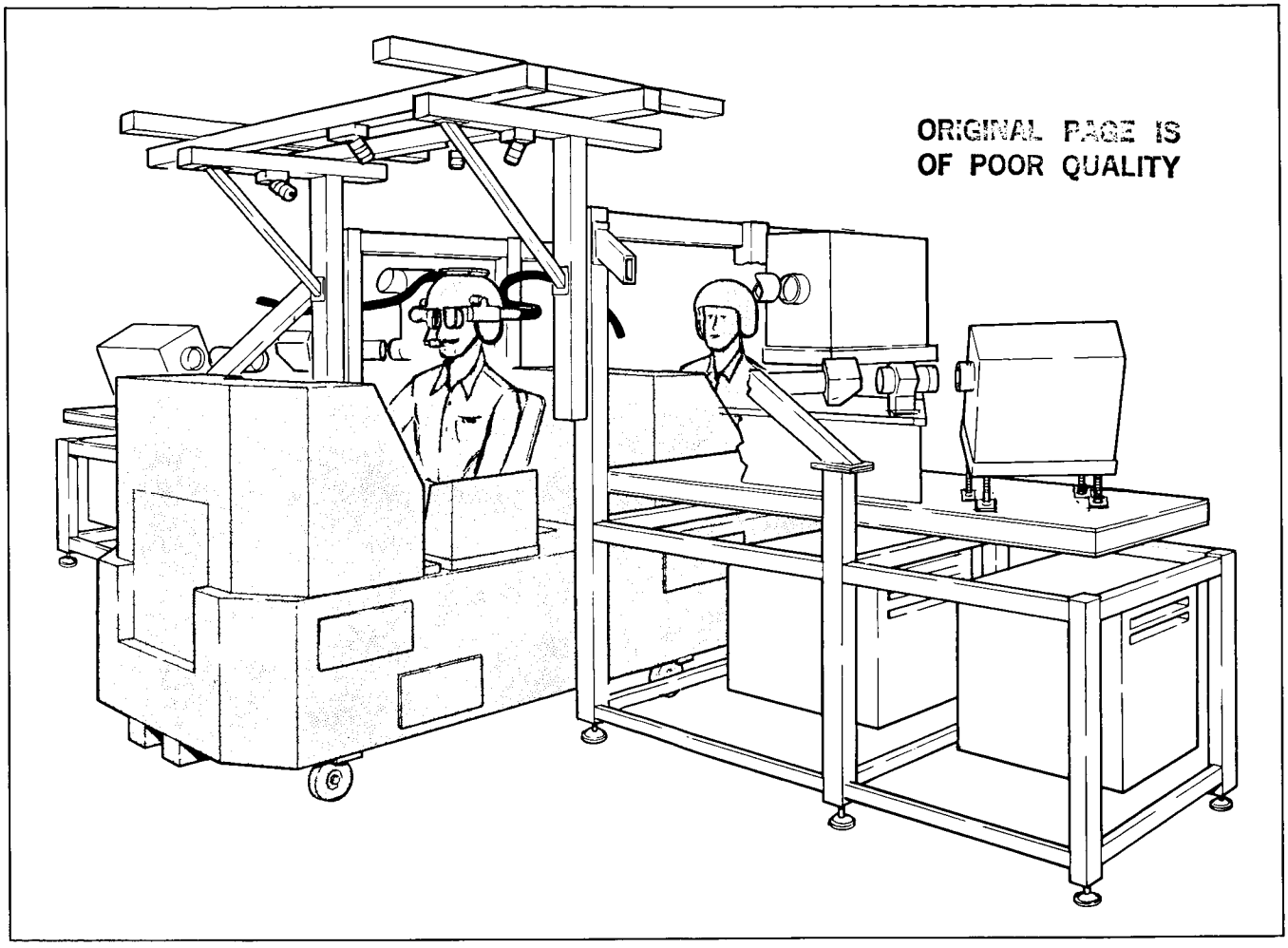
The Crew Station Research and Development Facility (CSRDF) is an advanced full-mission simulator being developed in a multiyear joint program with Ames Research Center and the Army Aeroflightdynamics Laboratory. The initial use of the facility will be in direct support of the Army's LHX helicopter-development program. When operational, it will provide critical research data for the Army to help answer the one-person vs two-person cockpit question for the next generation light-helicopter development. For the long term, this unique fixed-base facility will provide NASA and the Army with a powerful research tool in the human-factors area for pilot workload studies, crew coordination issues, and provide a realistic simulation of the complexity and high workload involved in combat scenarios. It will also provide a facility to study advanced automation, to include glass cockpits, advanced helmet-mounted-display (HMD) concepts, and advanced graphics capabilities.

The CSRDF will consist of the following major elements:

1. A two-seat, tandem, fixed-base cockpit with advanced controls, electronic displays, and a fiber optic HMD system. This crew station can simulate the complete cockpit environment, including modern sensor displays, of any proposed advanced rotorcraft.
2. An advanced image-generation system (ATAC II DIG) built by Singer Link. This system will simulate day/night/forward-looking IR visual images for use in the cockpit or on an HMD.
3. A network of integrated computer systems, including an array processor, symbology generation, and modern operational consoles coupled with a sophisticated communications system.
4. Mission scenario software capable of realistic simulation of the tactical environment which can model the interactions of an 11-member scout/attack team against enemy aircraft and over 100 ground threats.

Major accomplishments this year for this fast-paced project have included:

1. An integration contract has been awarded to CAE Electronics, Ltd., of Montreal, who is developing hardware and software, providing the unique helmet, and integrating and delivering the entire equipment suite to Ames. Preliminary design review (PDR) and critical design review



Tandem crew station structure showing front seat pilot using the wide field of view fiber-optic HMD

(CDR) have been held and the system is undergoing final software and hardware integration. Government acceptance tests are scheduled for the second quarter of FY 87.

2. The award of a contract with Flight Systems, Inc. of Irvine, CA, to develop a real-time version of their government combat mission scenario software. PDR and CDRs have been held and software has been delivered to the Montreal test site. Final acceptance is scheduled in the first quarter of FY 87.

3. The award of a contract to provide the building modifications to house this facility with S&Q Corp., Mountain View, CA. Major construction is under way, with scheduled completion in the third quarter of FY 87.

(D. Jones, Ext. 4027)

UH-60A Accident Investigation

The Army Aeroflightdynamics Directorate (AFDD) at Ames Research Center was tasked with conducting a simulation of the UH-60 Black Hawk helicopter in support of the investigation of a March 11, 1986, accident near Ft. Rucker, AL. AFDD's assignment was to develop a piloted simulation using the vertical motion simulator (VMS) to evaluate automatic-flight-control system failures, and the effect of pilot control input responses with an acceptable level of fidelity to direct investigation efforts and suggest areas for subsequent testing. From reviews with the Army Aviation Safety Center and Sikorsky Aircraft, a test plan of configurations and flight regimes to be investigated ranging from vehicle step responses to full accident scenarios was generated. The Ames GEN HEL UH-60 math model had been refined and improved during the preceding 2 yr at Ames. However, more detailed improvements were required to reproduce the control system in sufficient detail to investigate possible failure modes of the stability-augmentation system, the flightpath stabilization system, the feel-and-trim system, and the horizontal stabilator. Close communication was maintained with and support received from both Sikorsky and the Army Aviation Safety Center throughout the development and conduct of the simulation.

The simulation occurred between June 23, 1986, and July 25, 1986. By documenting the vehicle response to control inputs and comparing the simulator response with flight-test data, the simulation math model was deemed to be of sufficient fidelity to continue exploring flight conditions corresponding to the accident descriptions. Preliminary findings include the demonstration of control input histories and flight conditions which could generate flightpaths closely approximating both the Ft. Rucker accident and a March 1985 accident at Ft. Bragg. Techniques developed in this study will be applicable to other accident investigations. In particular, the Army Aviation Safety Center is considering adopting the technique developed in this experiment of generating a video movie of the accident scenario from the simulator computer-generated imagery. The figure shows a scene from such a movie.

(M. Lewis and M. Ballin, Ext. 6115)

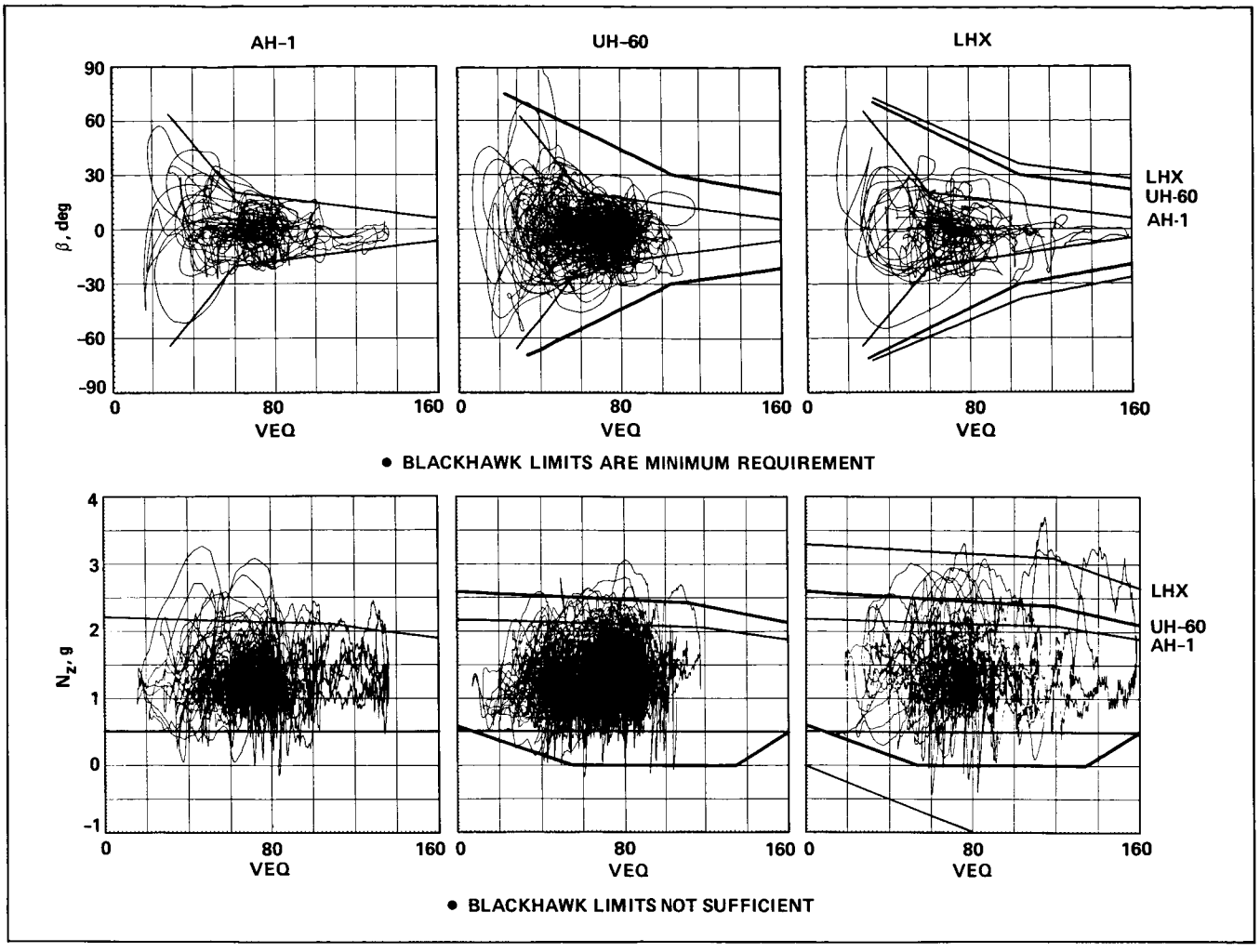
Simulator representation of UH-60A accident as seen from observer location

Helicopter Air-Combat II

A Helicopter Air-Combat (HAC) simulation was conducted to define the handling qualities and flight characteristics required for one-on-one helicopter air-to-air maneuvering and to provide additional data for the revision of the specifications for Handling Qualities Requirements for Military Rotorcraft. The experiment was conducted using the helicopter air-combat system originally developed for HAC-1 at Ames Research Center. The HAC system utilizes the six-degree-of-freedom, large-amplitude motion, vertical motion simulator (VMS) in conjunction with a fixed-base target-control station to simulate low-level, dual-piloted helicopter air combat.

Experimental variables for this simulation were aircraft maneuver envelope size (load factor and sideslip), cyclic control response type, and directional axis handling qualities. All of these variables were systematically altered to determine their effect on success in the air-combat task. Over 450 engagements were flown by evaluation pilots from the Army, NASA, and industry.

Results of the experiment indicate that relatively highly damped directional response, low sideforce caused by sideslip, and some effective dihedral are all desirable. A rate-command system



Data and conclusions (performance envelopes)

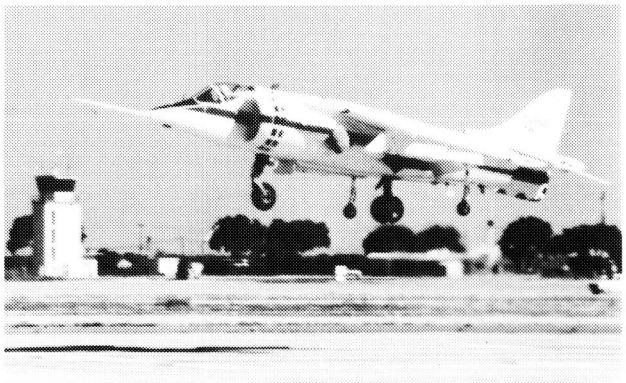
was favored over the attitude-type pitch-and-roll response for most applications, and an enhanced maneuver envelope size over current generation aircraft was found to be advantageous. Pilot technique, background, and experience were all determined to have played a role in their adaptability and success in the air combat task.

Further studies are being planned to investigate the effects of a more realistic weapon system, such as a turreted gun with ballistics, and the introduction of 1 vs 2 scenarios and automated opponents.

(M. Lewis and M. Mansur, Ext. 6115/6037)

YAV-8B Aerodynamic Modeling

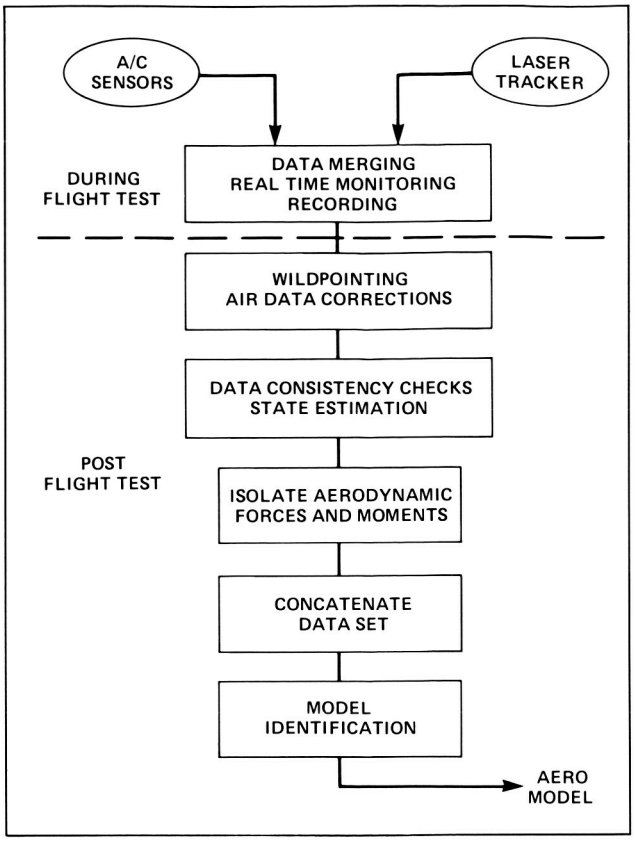
Ames Research Center is conducting a flight-research program on guidance, control, and display concepts for V/STOL aircraft. The program is directed toward extending V/STOL capability to include flight operations aboard small ships in adverse weather. The test bed for this research is a YAV-8B aircraft, acquired by NASA in April 1984. The YAV-8B is a prototype of the currently operational AV-8B Harrier, a carrier-based, subsonic,vectored-thrust, V/STOL fighter aircraft; its main engine nozzles can be rotated from 0° for forward flight to over 90° for hover. Compressor bleed air is piped to the extremities of the aircraft for attitude control and stabilization in hover and transition.



YAV-8B performing a short takeoff at the Ames flight-test facility, Crows Landing, CA

The first group of experiments to be performed with the NASA YAV-8B include extensive flight testing to provide a data base for development of a full-envelope aerodynamic model. This model will be used to update and improve the existing Harrier simulation, and to aid in the design of guidance and control systems for the aircraft. Both global and spline polynomial modeling schemes are being considered; a least-squares procedure will be used to identify model parameters. Flight data consistency will be ensured by using a postflight-state estimation program. Flight-test maneuvers that cover the operating envelope and that are feasible for a pilot to fly are being evaluated with the existing YAV-8B real-time flight simulator.

(D. McNally and R. Bach, Ext. 5440/5429)

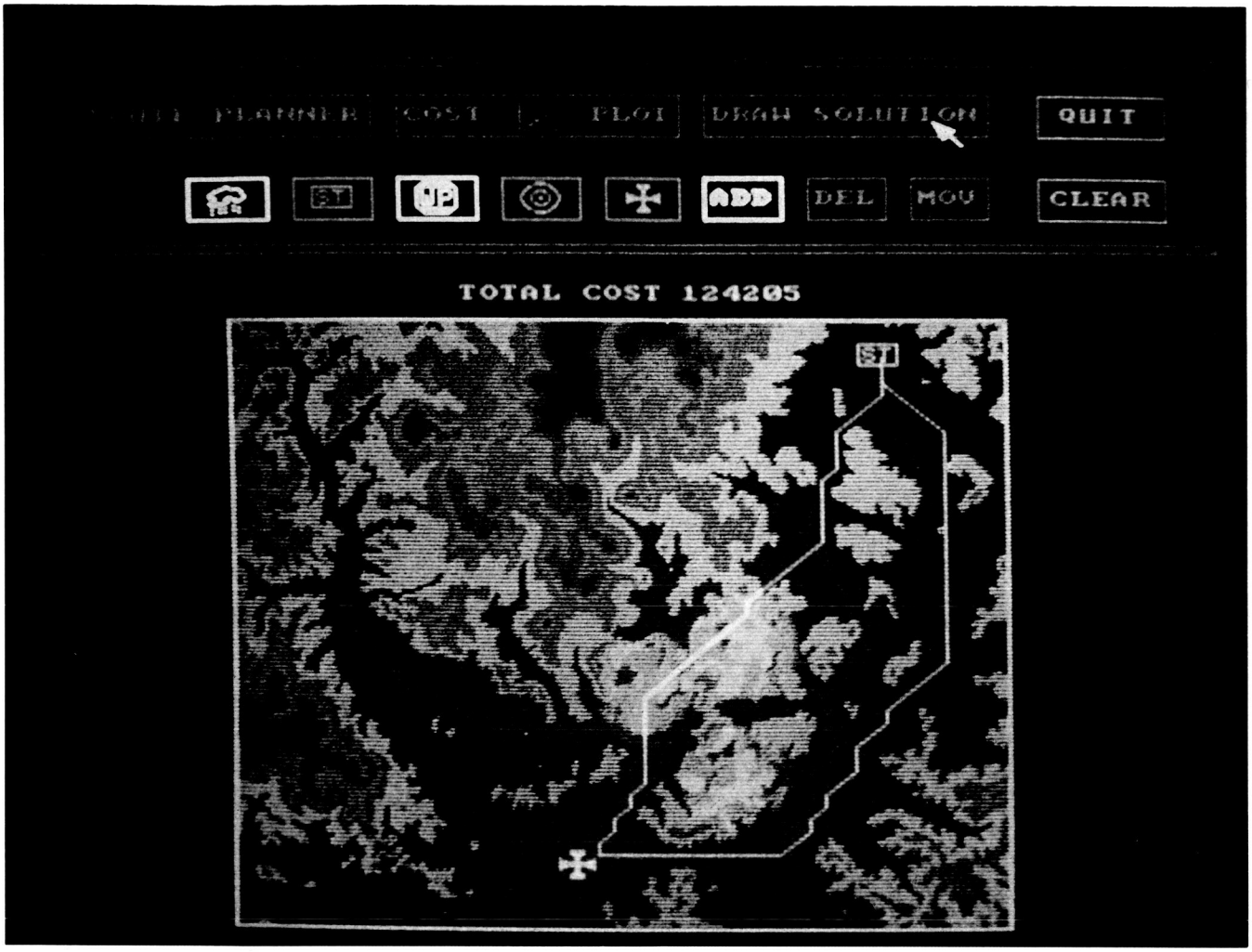


Data processing

Automated Path Planning/ Replanning for Nap-of-the-Earth Flight

A major goal of both military and civilian agencies is to reduce rotorcraft impacts with terrain or obstacles while performing automated nap-of-the-Earth (NOE) flights at night or in adverse weather with a single pilot. Achievement of this capability will require generating a planned path which meets numerous goals and conditions yet minimizes cost to the rotorcraft. Once created, the plan would be used by the on-board, real-time path-following system to generate terrain-following/terrain-avoidance (TF/TA) guidance commands.

Three automatic path plans are under development which will result in realistic routes to meet selection criteria, including transit speed, threats, obstacles, terrain features, and intervisibility effects when threat locations are uncertain.



Display from automatic path planner

The first plan, developed under contract with TAU Corp., uses a dynamic programming algorithm to achieve an optimal path. It is currently operational with additional features being incorporated. A second contract with the Charles Stark Draper Laboratory will develop a mission planner/replanner using a heuristically guided, simulated, annealing algorithm. This approach is expected to lead to a near-optimal method for very rapid replanning in emergency or rapid-response situations. A third method is being developed in-house at Ames which seeks to use an expert-system approach based on previous work with a planner for the C-141 aircraft and software developed by the Army A^3I program.

(L. McGee, Ext. 5443)

Transient Failure Simulation

A simulation experiment was conducted to validate, or generate, a data base to change the hypothesized transient failure criteria set forth in the specifications for Handling Qualities Requirements for Military Rotorcraft. This simulation was performed as a "piggyback" experiment with the Single Pilot Advanced Cockpit Engineering Simulation (SPACES II) on the vertical motion simulator (VMS) at Ames Research Center. Piggybacking on the SPACES II experiment offered the advantage of acquiring data from pilots who were not expecting failures to occur. The failures were injected into the automatic flight-control system of the existing advanced-digital/optical-control system (ADOCS) structure. All failures were single-axis "hardover" failures with varying levels of authority. After the failure was inserted into the system, the automatic system turned off and the pilot was left with the ADOCS primary flight control system.

Two evaluations took place after each failure. First, the pilots rated their ability to recover from the failure using a failure-rating scale developed by the experimenters. Second, the pilots rated their ability to perform the same task as prior to the failure with the degraded flight control system. The pilots used the Cooper-Harper rating scale for the second evaluation.

Failures were introduced that produced transient responses which fell within the categories of the current revision to the specifications for Handling Qualities Requirements for Military Rotorcraft. Failures were also introduced that did not fall within the above categories to provide a complete data base.

Results from the experiment show that the current specification is valid for the pitch and roll axes at hover. The results at forward speeds (60 knots) for the pitch and yaw axes are inconclusive. For the lateral axis at forward speeds, the criterion needs to be redefined. In the simulation, higher lateral axis attitude excursions were more tolerable than stated in the specification. Specifications for the vertical axis also need to be redefined based upon these data. At low-altitude hovers, every Level 2 and Level 3 failure from the proposed specification injected into the system resulted in a crash. The acceptable levels of vertical acceleration for these two levels need to be reduced from 0.2 and 0.4 g in 3 sec to 0.07 and 0.1 g, respectively.

Transient failure simulator

1. Simulation examined the validity of the current proposed transient failure criteria.

2. Experiment was performed in a high-workload environment.

3. Failures were injected into the ADOCS structure.

4. New failure-rating scale was developed for the experiment.

5. Specification was validated at hover for pitch and roll axes.

6. Tolerances for vertical-axis failures are currently too severe.

7. Current high-speed lateral axis tolerances are too benign.

(J. Schroeder and M. Mansur, Ext. 4037/6037)

Nonlinear Inverse Model Controller for High-Performance Aircraft

The automatic control system for high-performance and highly nonlinear aircraft was modified to use a Newton-Raphson model inversion technique and was applied to a simulator study of control of a proposed Navy vertical-attitude takeoff and landing aircraft (VATOL). The system gave good control over the entire flight envelope as the aircraft went from conventional flight to vertical-attitude hover. Good control was maintained as the aircraft passed through lift curve slope reversal at about 30° angle of attack and kept constant altitude as the lift transitioned from aerodynamic to engine-thrust support. Good control was also achieved for conventional flight in steep climbs and turns of 2 and 3 g as well as in transition from vertical attitude hover to conventional flight. Precise maneuvering in all directions was demonstrated in vertical-attitude hover.

These tests, as well as other simulations and flight tests in several nonlinear aircraft configurations, have demonstrated the promising potential of this control-system concept for such demanding tasks as automatic night landing on a carrier at sea, terrain-following by a helicopter, or control of cruise missiles and remotely piloted vehicles.

The concept has also shown good performance when controlled in real time by a human pilot using a side stick controller to command trajectory accelerations and/or velocities.

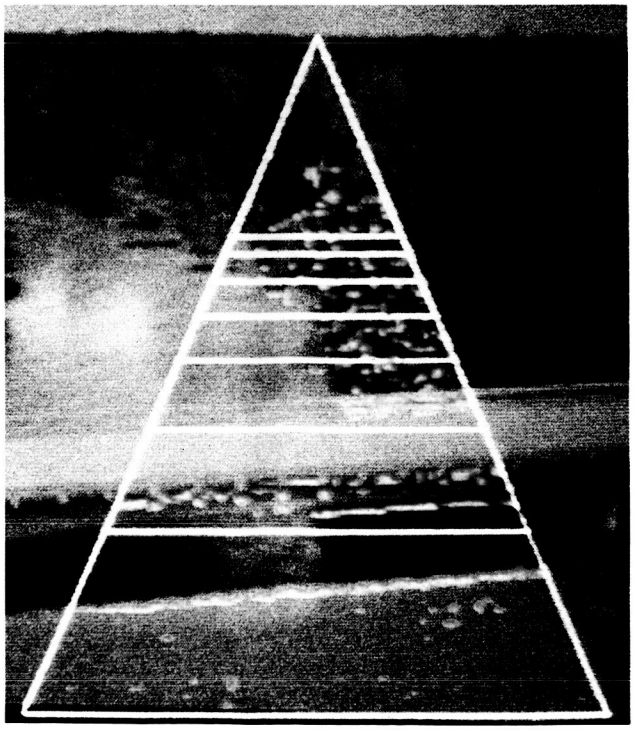
(G. Smith, Ext. 5446)

Sensor Integration/Interpretation

Low-altitude, nap-of-the-Earth rotorcraft flight with its extreme proximity to the ground, where terrain, wires, and other obstacles are a major consideration, presents a difficult challenge to the sensor subsystem. The goal of Sensor Integration/Interpretation research is to develop methods to recognize terrain features, obstacles, landmarks and targets, and integrate this information with on-board navigation data to assist in low-altitude flight. This is achieved by using techniques from digital image processing and computer vision to extract information from imaging sensors, e.g., forward-looking infrared (FLIR), millimeter wave, laser, etc.

Assuming the knowledge of rotorcraft velocity, using triangulation, the range between an object on the ground and the rotorcraft can be related to the changes in azimuth and elevation of the object in two FLIR images taken at different instants. An efficient collision-avoidance algorithm has been developed using the triangulation principle and the notion of a safety zone around the helicopter. The advantage of this approach is that it limits the range estimation to a narrow region of interest. The sensitivity of this algorithm to variations in system parameters, quality of FLIR data, and on the field of view is currently under evaluation.

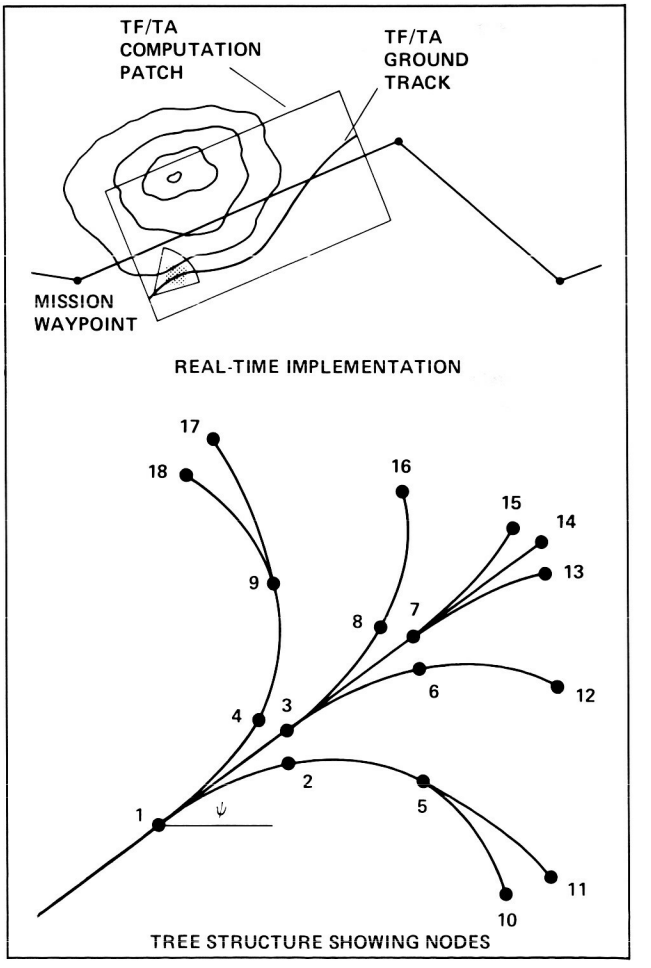
(B. Sridhar, Ext. 5450)



Display of obstacles in the rotorcraft path

Helicopter Terrain-Following/Terrain-Avoidance Flightpath Guidance

Helicopters that operate in threat areas have a need for low-level, maneuvering, penetration capability. Terrain-Following/Terrain-Avoidance (TF/TA) Systems, whether implemented automatically or by a flight director can provide this capability, and therefore can increase overall



Terrain following/terrain avoidance dynamic programming

mission survivability. Research is being conducted to develop and evaluate a TF/TA flight-guidance system along with the associated flightpath control laws and pilot display requirements for manual and automatic rotorcraft flight.

A TF/TA guidance algorithm originally developed for tactical and strategic fixed-wing aircraft was modified to reflect the dynamics and constraints of helicopters. The algorithm, a dynamic programming technique, incorporates an aircraft trajectory that takes advantage of local terrain features for optimal terrain-masking during contour flight operations at or below 100 ft altitude AGL. The guidance algorithm projects a 30-sec trajectory, updated every 3 sec, which is based upon current aircraft states, a digital terrain map, navigation waypoints, and selected helicopter performance parameters. A computer simulation that integrated the TF/TA trajectory guidance algorithm, a six-degree-of-freedom helicopter model, and a path-following automatic control system yielded acceptable performance results for automatic helicopter operations.

A piloted simulation using the TF/TA algorithm was scheduled for October 1986. The simulation was conducted on the Ames Research Center's Vertical Motion Simulator. The simulation will explore the pilot display and control requirements for TF/TA flight operation for automatic, flight director, and manual helicopter operations. Results of this simulation will aid in the development of systems for the automation of nap-of-the-Earth flight.

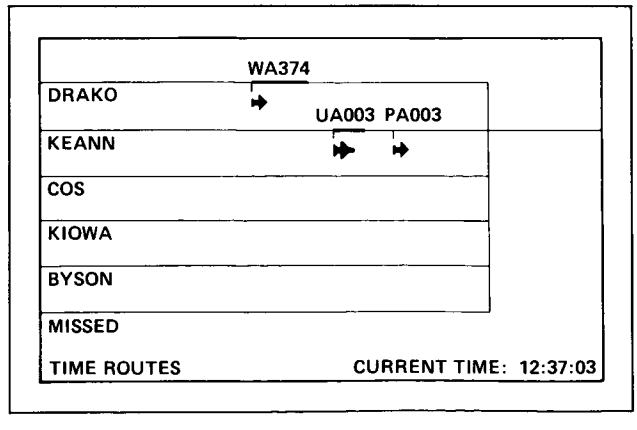
(H. Swenson and D. Dorr, Ext. 5424/5452)

Time-Based Air-Traffic Management Using Expert Systems

At present, the decision-making process of air traffic control (ATC) in the extended terminal area (from 150 n. mi. away from touchdown until touchdown) is a manual one. Controllers expertly direct traffic flow to maximize capacity without compromising safety by issuing to each aircraft clearances which specify speed, altitude, or heading requirements. In terms of arrivals to a single runway at a major terminal area, this is generally accomplished as follows: along each of the three to four major arrival directions, traffic is spaced uniformly. However, the traffic flows from the various arrival directions are uncoordinated. It is the responsibility of the final controller to take these uncoordinated flows and establish a sequence of traffic which does not violate separation constraints between consecutive aircraft.

In order to provide the controller with assistance in scheduling aircraft arrivals, Ames Research Center has been investigating the use of expert-systems methodology to assist in the planning process. A prototype expert system has been developed for the time scheduling of aircraft into the terminal area. The three functions of the ATC schedule advisor are as follows: first, for each new arrival, it develops an admissible flight plan for that aircraft. An admissible flight plan is one which provides a schedule which is feasible for that aircraft type; in addition, the aircraft must not conflict with its neighboring flights and, in fact, the minimum time separation between neighboring aircraft (which depends on the weight categories) must not be violated. Second, as the aircraft progresses through the terminal area, it monitors deviations from the aircraft's flight plan and provides advisories to return the aircraft to its assigned schedule. Third, if major disruptions such as missed approaches, blocked runways, or requests for emergency landing occur, it develops a revised plan. The advisor is operational on a Symbolics 3675, and is programmed in ART (an expert-system development shell), LISP, and FORTRAN. NASA and the FAA plan to evaluate the schedule advisor under live traffic conditions at an Enroute ATC Facility.

(L. Tobias, Ext. 5430)



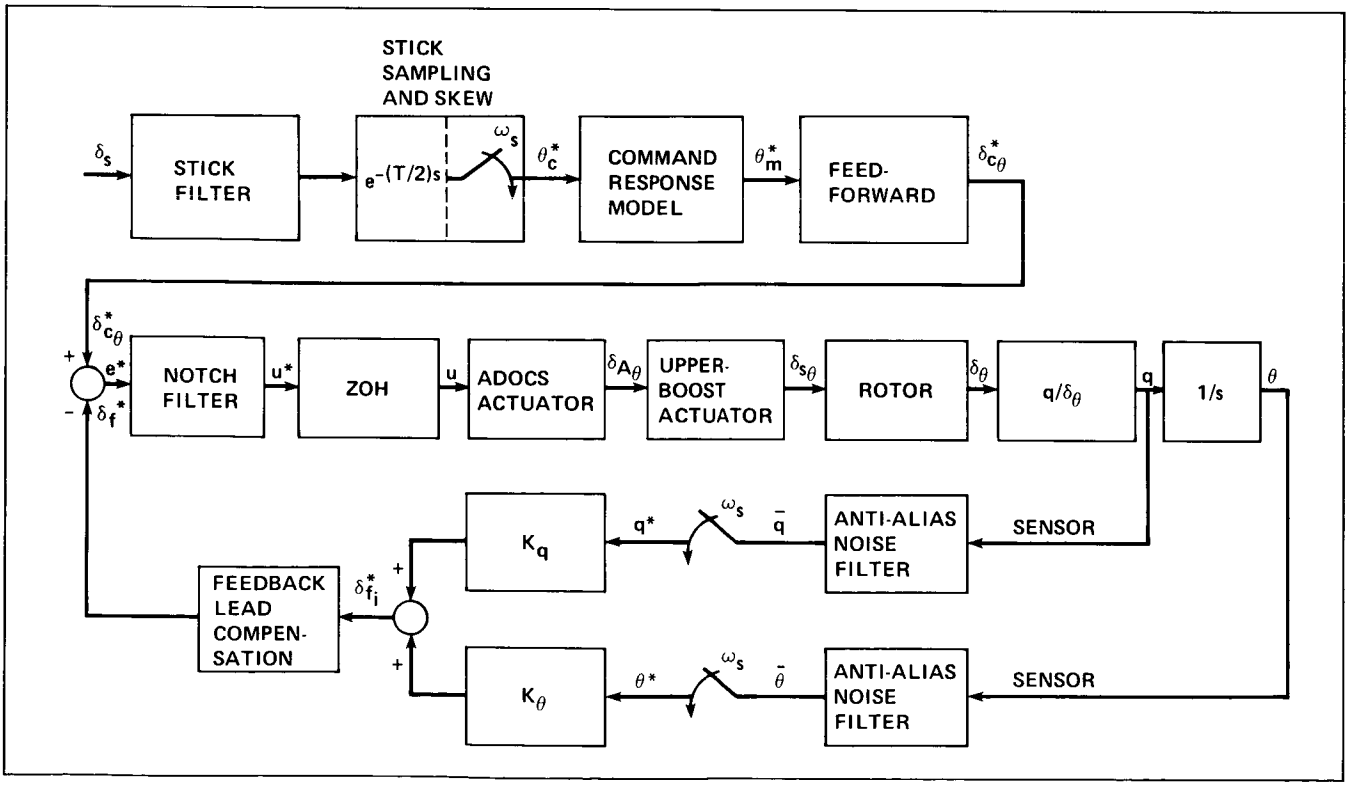
Time line scheduling control display

Digital-Control Technology

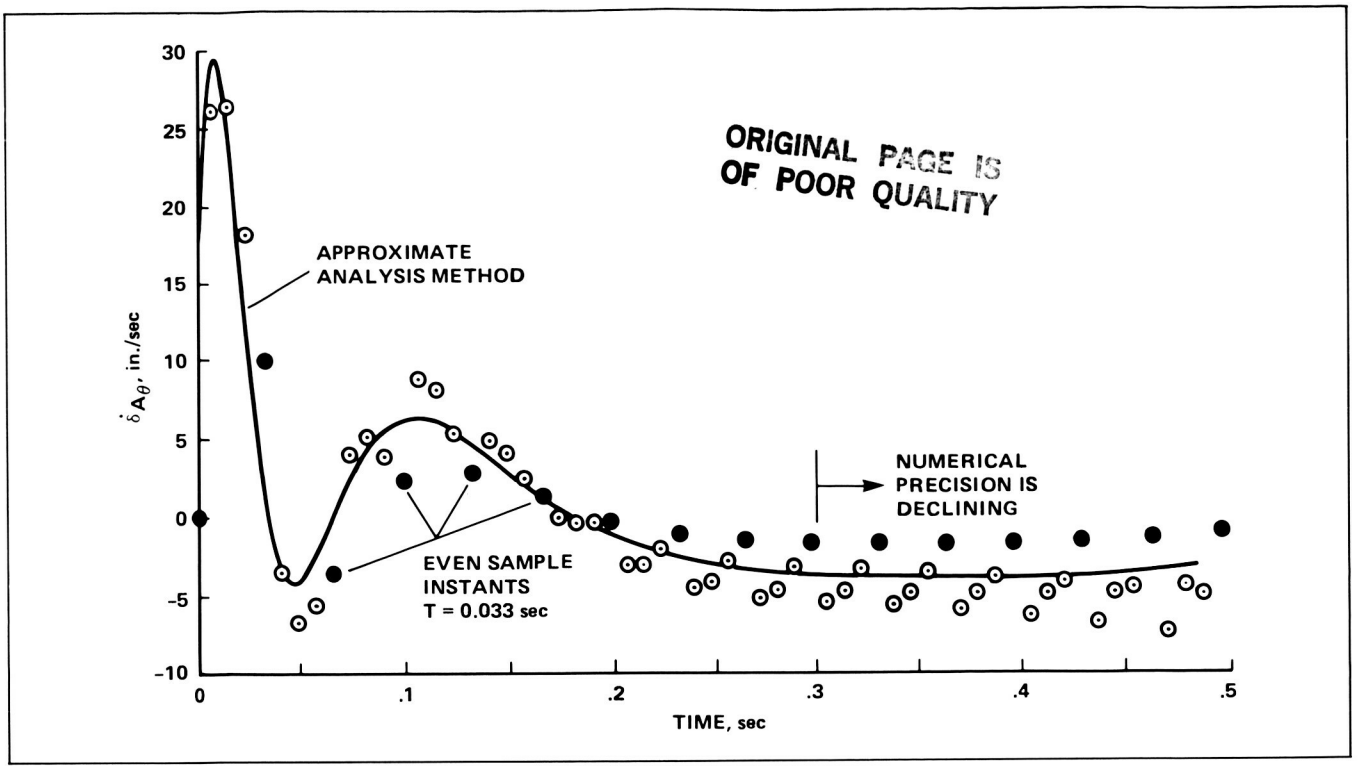
Proposed concepts for the scout/attack aircraft (LHX) and joint/service tilt rotor aircraft (JVX) are embodied in a complex, highly maneuverable, multirole vehicle with avionics systems which are as important to mission success as the airframe itself. Single-pilot and nap-of-the-Earth operations require handling qualities which minimize the involvement of the pilot in basic stabilization tasks. These requirements demand a full-authority, high-gain, multimode, digital, flight-control system. The gap between these requirements and current low-authority, low-bandwidth, flight-control rotorcraft technology is considerable. Ongoing research aims at smoothing the transition between current technology and advanced concept requirements.

An extensive technical document entitled "Digital Control of Highly Augmented Combat Rotorcraft" has been prepared. This document reviews the state of the art in fixed- and rotary-wing flight control, and discusses a comprehensive case study based on the advanced-digital/optical-control system (ADOCS) Black Hawk. Methods for analyzing and designing high-bandwidth digital-control systems are discussed and illustrated. The figure is a schematic of a typical attitude-control system, including the many elements needed for a practical digital-system implementation. The response of the actuator rate ($\dot{\delta}_{A\theta}$) to a step-command input at $\delta_{c\theta}$ is shown in the second figure (30-Hz system). The solid curve is the result obtained using approximate (continuous-system) methods. The digital-system exact response is shown as open and closed dots, the latter being the response at the even sampling instants. This figure shows that the even-sample instants are a very poor reflection of the complete digital-system response. The approximate analysis gives a fairly good estimate of the intersample behavior, although the level of "roughness" is underestimated. Flight tests of the ADOCS Black Hawk took place in late 1986 to validate and complement the analytical studies.

(M. Tischler, Ext. 5563)



Pitch axis, digital control system

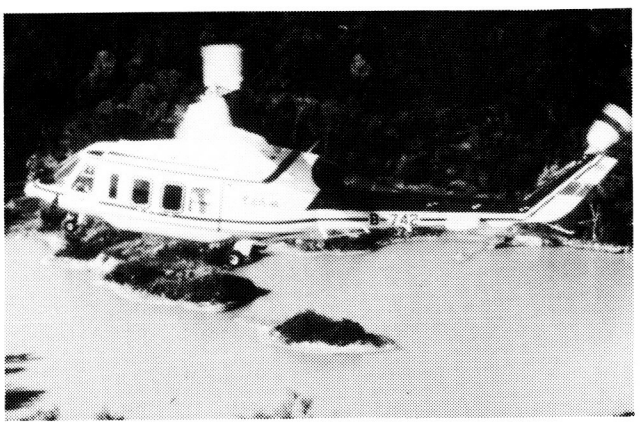


Actuator rate ($\dot{\delta}A_\theta$) response to a step input, $\delta_{c\theta}$ = 1 in.

Demonstration of Frequency-Sweep Testing Technique Using a Bell 214-ST Helicopter

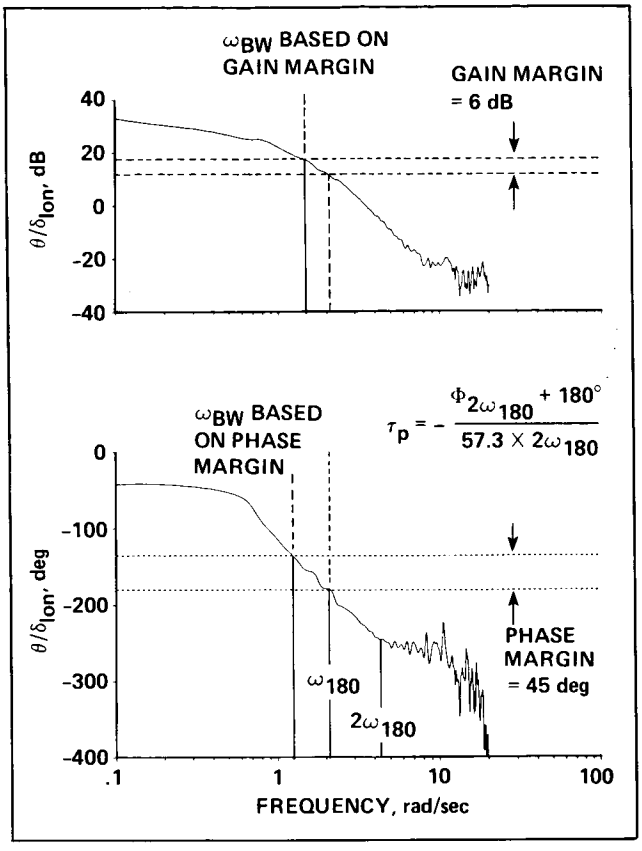
Research supporting the development of the scout/attack aircraft (LHX) handling-qualities specification (an updated version of MIL-H-8501-A) indicates the need for frequency-domain descriptions to adequately characterize the transient angular response dynamics of highly augmented combat rotorcraft. The proposed LHX criteria for short-term angular response is given in terms of two frequency-domain parameters — bandwidth (ω_{BW}) and phase delay (τ_P). These quantities are read directly from frequency-response plots of the on-axis angular responses to control inputs. Such plots are easily generated from analytical models and are useful design tools; however, a key concern in incorporating such descriptions in a specification compliance requirement is the practical concerns associated with extracting the frequency responses from flight data.

A flight-test demonstration program (6 flight hr) using an instrumented Bell-214-ST helicopter (first figure) was conducted in October 1985.



Bell 214ST

Frequency-sweep and step-input tests were conducted in hover and cruise (90 knots) for each control axis. The data were subsequently analyzed using dynamics identification software developed at the Ames Research Center. Excellent identification of the frequency responses was achieved for all axes at both flight conditions. As an example, the extracted response of pitch-attitude to longitudinal cyclic stick is shown for the hover flight condition (second figure). An accurate spectral estimate is achieved over a broad



Identified pitch response, θ/δ_{long}

frequency range (0.2–10.0 rad/sec), and the required specification compliance parameters are easily obtained. Additional analyses were conducted to identify transfer-function models for each axis. These models accurately predict the large-amplitude step-response behavior, and validate the linearized frequency-response concept for single-rotor helicopter. The flight-data analysis has been completed. All of the above objectives were achieved and no further tests on this vehicle are planned.

(M. Tischler and J. Fletcher, Ext. 5563/5836)

Application of Quadratic Optimal Cooperative Control Synthesis

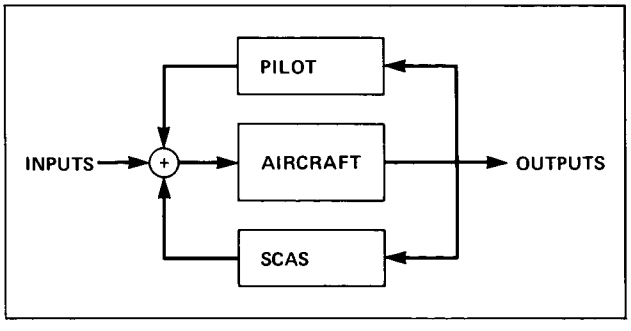
A new control design methodology (quadratic optimal cooperative controller synthesis, or CCS) was evaluated and compared with other existing design methods. The perceived advantages of CCS are the elimination of detailed a priori design criteria, and the ease of application to higher-order models. CCS has been used previously in the design of a stability and control augmentation system (SCAS) for two different fixed-wing applications (fourth-order), and evaluated in fixed-base, piloted simulations. For this research, the method was simplified and modified for application to an eighth-order helicopter model.

In CCS, the pilot model is based on a description of the desired task, then the SCAS is designed to minimize the workload of the pilot model while limiting the SCAS control inputs. Linear quadratic regulator theory is used for the SCAS design, but an output feedback solution (rather than full state feedback) is necessary. The requirement of output feedback in the SCAS solution makes the CCS design process iterative. The controller design process is illustrated in the figure.

The application chosen for evaluation was an eighth-order model of the Boeing CH-47 helicopter model, linearized at an airspeed of 60 knots. Two CCS designs were obtained (using the unmodified and modified CCS methods), and compared with two other designs based on frequency domain-classical methods and linear quadratic regulator (LQR) theory. Results from a fixed-base, piloted simulation indicate that the modified CCS design method compares favorably with the frequency domain-classical method (which was obtained using detailed a priori design information), and was superior to LQR design.

Future work using CCS is tentatively planned in several areas, including possible in-flight evaluation of the CCS design, and applications of the design method to different flight conditions and higher-order helicopter models.

(B. Townsend, Ext. 5563)



Design method problem description

Rotorcraft Cross-Coupling

The Rotorcraft Cross-Coupling (ROXC) program is intended to assess the effects of variations in pitch-roll cross-coupling characteristics on handling qualities for hover and low-speed maneuvering.

Although cross-coupling is generally acknowledged to be a limiting factor on the ability of a pilot to exploit the full maneuvering capability of single-main-rotor helicopters (especially those with high equivalent hinge offsets), little or no data exist to support the appropriate design criteria. Accordingly, a ground- and in-flight simulation program is being conducted to generate the required handling-qualities data. A simplified analytical model of a generic, single-main-rotor helicopter in hover has been developed to gain a fundamental understanding of the physical processes which contribute to the pitch-roll cross-coupling response characteristics, and the effects of variations in rotor design parameters (such as hinge offset, flapping hinge restraint, pitch-flap coupling, and control advance angle).

A similar model has been implemented for piloted simulation in the Ames Research Center vertical motion simulator (VMS) during the period June 23 to July 25, 1986. The effects of large variations in rotor design parameters are being investigated for hover and low-speed tasks such as sidesteps, quick stops, and slaloms. Both NASA and Army test pilots from Ames participated as evaluation pilots; in addition, under the auspices of the U.S./German Memorandum of Understanding on Helicopter Flight Controls, a test pilot from the German Aerospace Research Establishment (DFVLR) is also taking part in the experiment.

In-flight simulation will be employed to validate the VMS handling qualities results using both the NASA/Army CH-47B variable stability helicopter at Ames and the DFVLR variable-stability Bo-105 helicopter in Germany. These flight tests are scheduled for the first quarter of FY 1987.

(D. Watson and E. Aiken, Ext. 4037/5362)

Investigation of Severe Turbulence Encounters at Cruise Altitudes

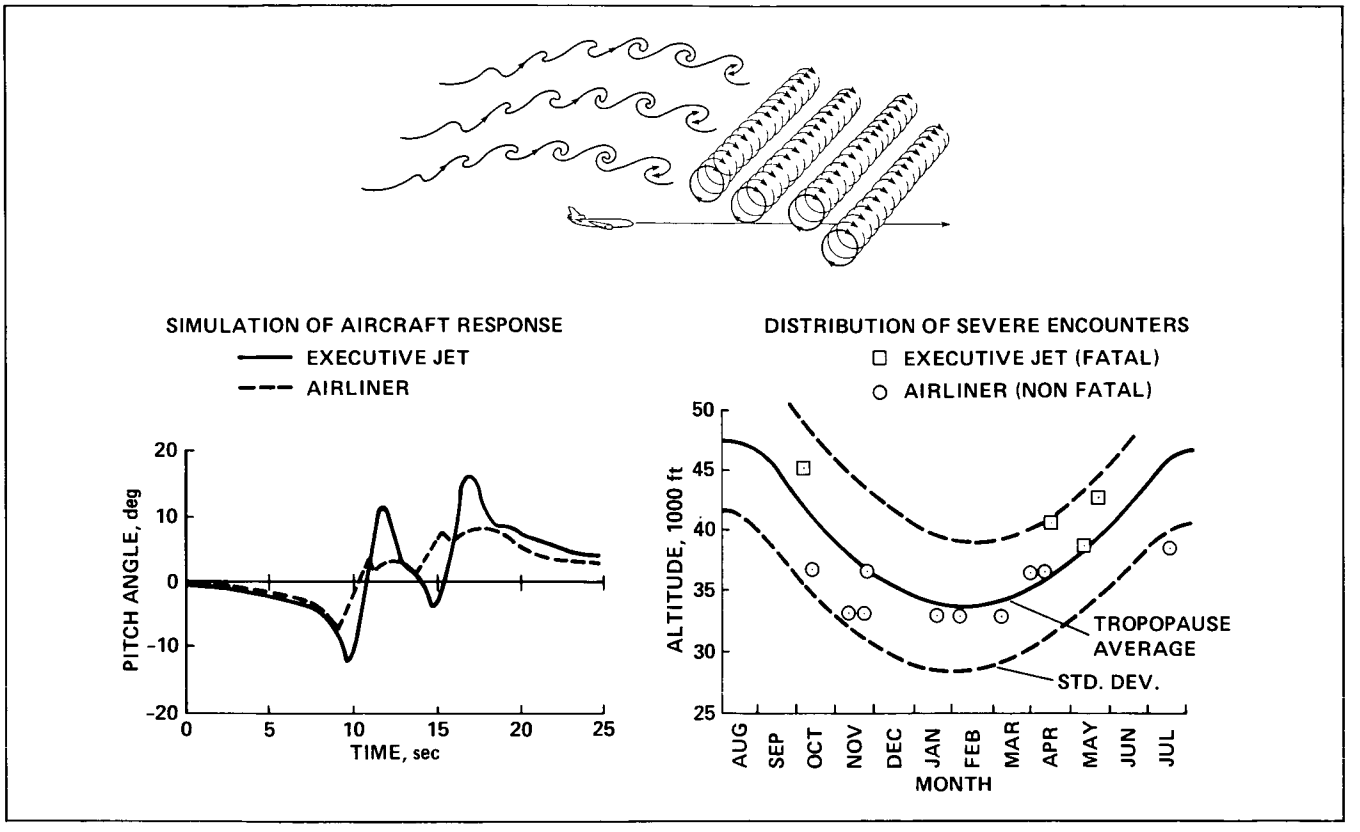
Severe atmospheric disturbances at cruise altitudes are a continuing problem that must be better understood in the interest of aircraft safety. One way to investigate the nature and cause of severe encounters is through analysis of airline flight records. In the past, such an analysis was hindered by insufficient data, but more recent turbulence encounters have involved modern airliners with digital flight-data recorders. These digital records, along with Aircraft Traffic Control (ATC) position records, provide a means to determine and analyze the turbulent wind environment.

In cooperation with the National Transportation Safety Board, a team of engineers and meteorologists at Ames Research Center is utilizing airline data to provide new insight into atmospheric disturbances that cause serious operating problems for aircraft. Using the flight records from a series of severe turbulence encounters in high-altitude cruise, the team has established that extreme turbulence is caused by vortex arrays generated by wind-shear layers near the tropopause. The team has identified the strength, size, and spacing parameters of vortex arrays, thereby providing a means to study the effects of these severe wind hazards on operational safety.

These vortex models obtained from the airline flight records are used to simulate and investigate the operational problems for the several types of aircraft that may unexpectedly encounter severe turbulence. Recent simulation studies involving vortex-induced turbulence have found that the smaller executive jets are subject to more violent dynamic behavior than the heavier airliners. Simulator studies will next be used to investigate possible operating problems for the new generation of smaller and lighter turboprop aircraft now being certified to cruise at the higher altitudes near the tropopause.

As compared to the somewhat lower cruising altitudes in the past, today's airliners cruise at higher altitudes with more flight time in the region of the tropopause. Modern airliners with digital recorders are probing much of the Earth's atmosphere in this region where the most severe cases of turbulence are usually found. Ongoing studies using airline data from severe encounters near the tropopause include a series of cases involving Pan Am 747s over Greenland (January, February, and November 1985), along with cases involving a United 747 off Hawaii (March 1986) and a Sabena DC-10 over upstate New York (April 1986).

(R. Wingrove and R. Bach, Ext. 5429)



Investigation of severe turbulence encounters

Flight Operations

A New Flying-Qualities Criterion for Landing

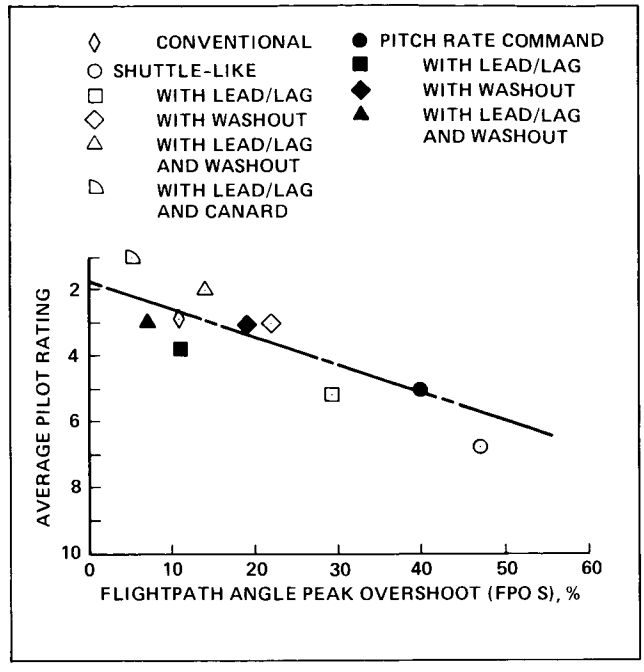
In recent years virtually all advanced aircraft have utilized pitch-rate-command flight-control systems. Pilots newly introduced to these aircraft have a strong tendency to float or balloon on landing. Some analysts believe this is only a familiarization problem that is due to unconventional response, and that can be overcome with training. Others believe these systems have a basic flying-qualities deficiency and should be designed more like conventional aircraft.

Recent studies at the Ames-Dryden Flight Research Facility have shed light on this controversy. Time histories of various aircraft response parameters for a pilot input representative of a landing-flare maneuver were analyzed and correlated with the results of in-flight simulator landing studies. It was found that pilot ratings correlated very well with a flightpath angle peak overshoot parameter (FPOS). This correlation is attributed to the fact that flightpath angle overshoot is an indication of the predictability of the flightpath response. If the aircraft acquires – with little or no overshoot – the flightpath that the pilot sees on neutralizing the controls, he or she can easily predict the response. On the other hand, if the aircraft significantly overshoots the flightpath angle that the pilot sees when he or she releases the controls, the plane will tend to float and balloon.

The illustration shows a typical correlation of the FPOS parameter for a variety of aircraft dynamics, including configurations with pitch-rate-command systems, Space Shuttle-like dynamics, lead-lag and washout filters, a canard, and a conventional aircraft. It can be seen that the pilot ratings correlate very well with this metric despite the wide variety of configurations. These results also indicate that a conventional response is not necessary so long as the FPOS is restrained to a reasonable value.

These data will make possible the development of design guides and criteria for advanced control systems that will ensure good flying qualities during landing without restricting the design to conventional responses.

(D. Berry, Dryden Ext. 3140)



Typical trend of pilot ratings with flightpath angle peak overshoot

Advanced Real-Time Test Techniques for Flight Research

The process of initial envelope clearance for research aircraft often requires new testing and monitoring techniques. The X-29A forward-swept-wing technology demonstrator has been flying since its first flight with a negative static margin in excess of 35%, a value that is unprecedented for manned aircraft. This level of static instability requires careful monitoring of the longitudinal dynamic characteristics of the aircraft and a comparison of these characteristics with predicted response throughout the initial envelope clearance. Furthermore, it was desirable to accomplish this in real time for flight safety and efficiency. Both the time-domain characteristics of the X-29A were monitored by using a high-speed digital computer which was tied to a telemetry receiving station, a high-speed vector processor, and a high-resolution, color-graphics system.

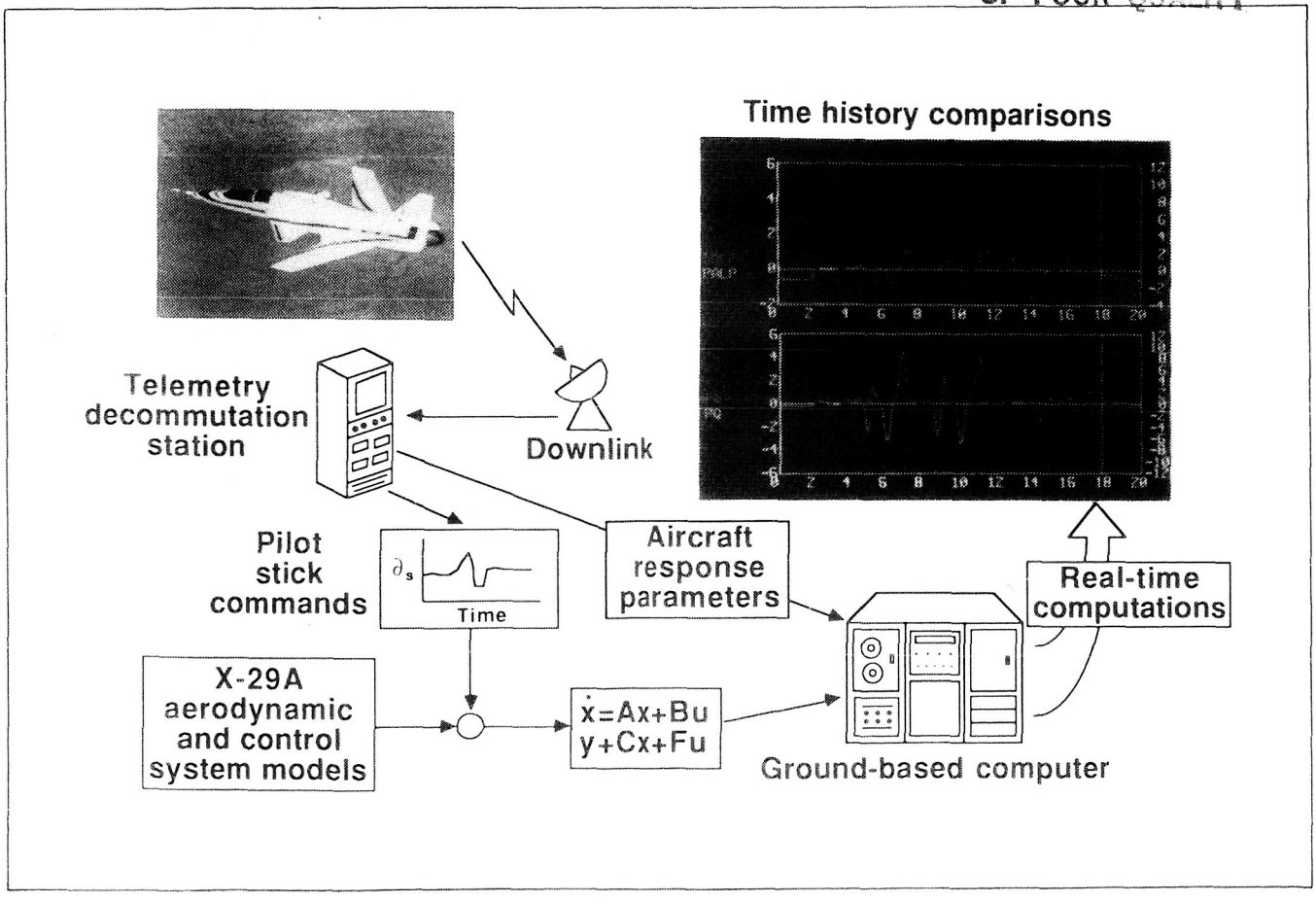
Comparisons in the time domain were accomplished by precomputing the linear difference equations of motion for each clearance test point. The pilot input to drive these equations was telemetered to the ground-based computer along with the principal motion variables. The computed and actual motion variables were

C-2

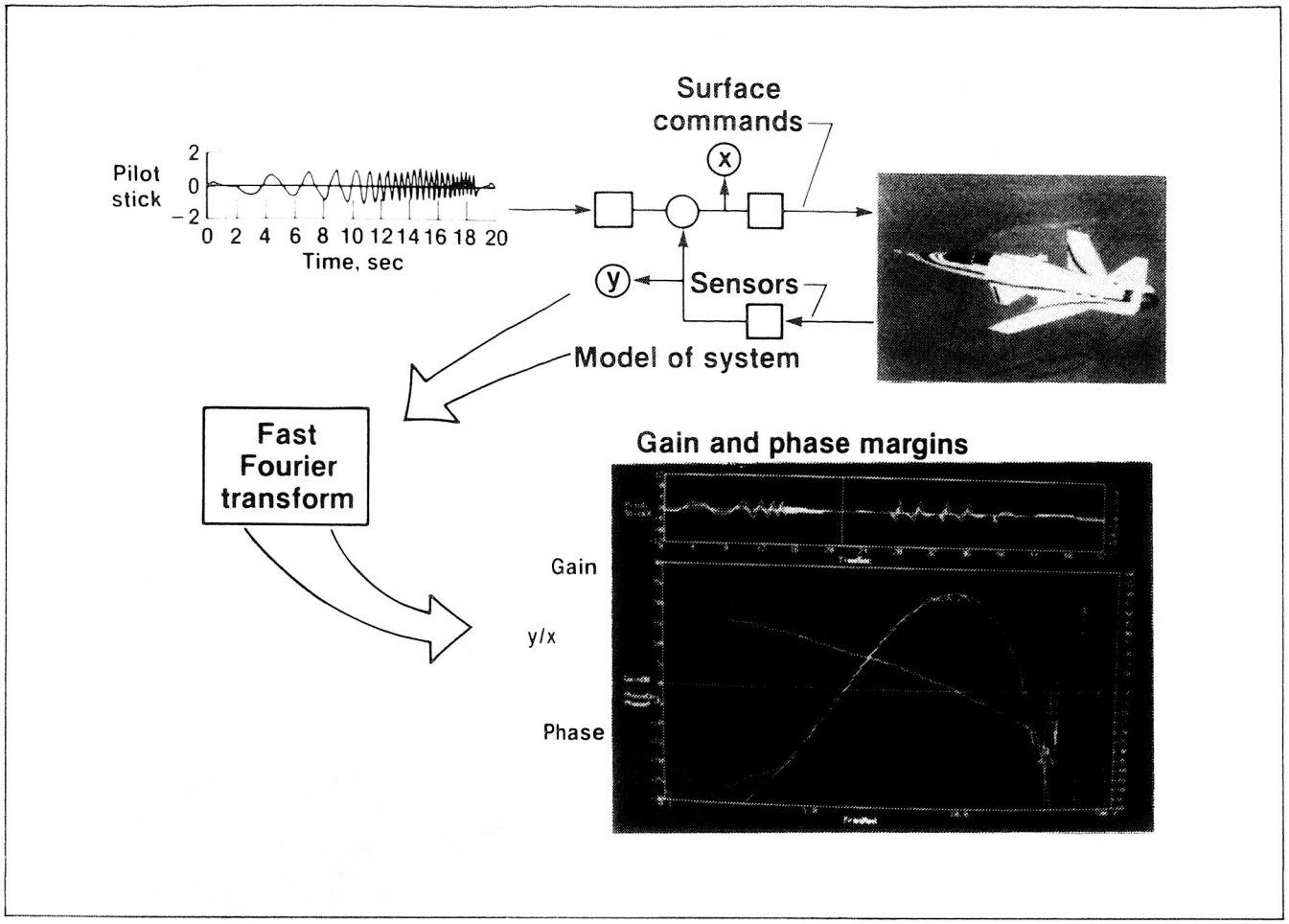
plotted in real time on the color-graphics terminal. These plots allowed a quick comparison of flight dynamics with predicted dynamics. The comparison also allowed isolation of any significant nonlinear airplane behavior which may be caused by surface saturation, actuator rate limiting, etc. Any large differences constituted sufficient cause to halt further expansion.

The frequency domain characteristics were monitored by measuring the longitudinal open-loop frequency response of the X-29A in real time. The X-29A was excited by a pilot-generated frequency sweep. Time histories of the input and output to the open loop system were telemetered to the ground-based computer. The data were transformed to the frequency domain using fast Fourier transformation techniques. The results were displayed on the color-graphics system along with precomputed predicted results obtained from linear analysis. The whole process from the end of the frequency sweep to the finished plot took less than 5 sec. The plot provided a measure of the stability margins of the X-29A at the specific flight condition and also provided immediate comparison with the linear model. With this tool, the stability at each new test point was assessed in near real time and, if the margins were high enough, the X-29A was cleared to the next flight-test point. With both the frequency and time-domain analysis tools operational, the pace of the X-29A envelope expansion program was significantly increased.

(J. Bosworth, Dryden Ext. 3792)



Real-time comparison of linear simulation to flight



Flight-determined frequency response for unstable airframes

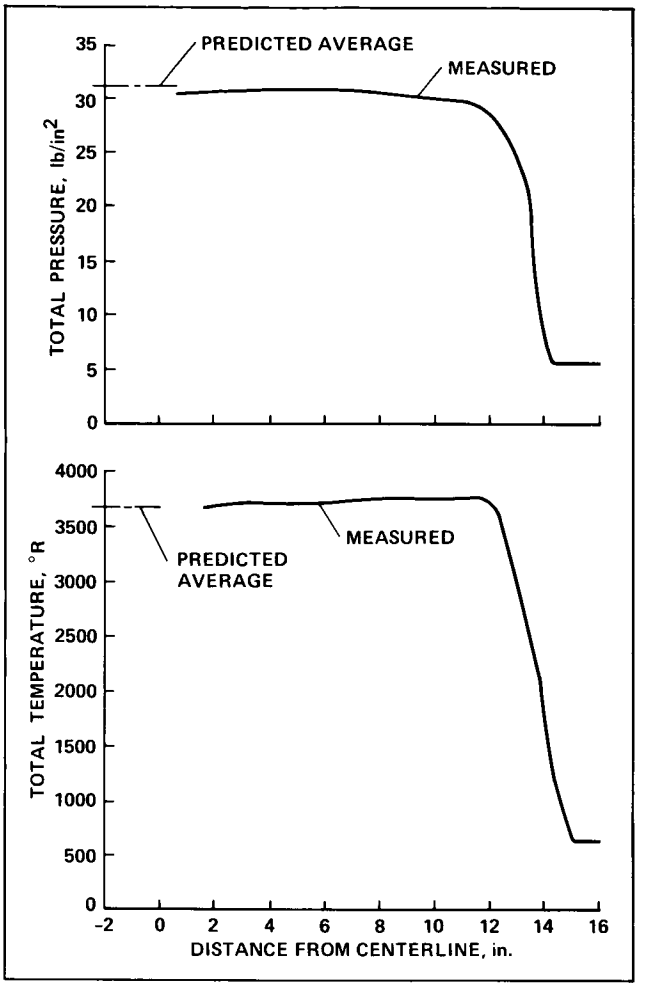
Exhaust Pressure/Temperature Survey of an Afterburning Engine

Exhaust temperature and pressure are key parameters in the design of thrust vectoring or deflecting systems planned for future highly maneuverable vehicles. In support of such future flight research, NASA Ames-Dryden and NASA Lewis conducted an exhaust gas temperature and pressure survey on an F404 afterburning turbofan engine. The F404 powers the F-18, the F-20, and the X-29A.

The engine exhaust survey was performed in the NASA Lewis Propulsion System Laboratory at two flight conditions and for power settings from intermediate to maximum afterburning. The pressures and temperatures were measured by a water-cooled traversing rake. Pressure and temperature data were corrected for flow radiation effects, and the results were compared to values predicted by the engine manufacturer's in-flight thrust program. Typical results are given in the figure, showing total pressure and corrected total temperature for a traverse from the edge of the jet to the engine centerline for a maximum afterburning condition. Good agreement between the predicted and measured pressure and temperature data is shown. The gradients in the flow near the edge of the jet are well defined.

This survey information is being used to define the design criteria for thrust-deflecting vanes being developed for the NASA High Angle of Attack Research Vehicle (HARV).

(F. Burcham and J. Walton, Dryden Ext. 3126)



F404 exhaust temperature and pressure data, maximum afterburning power, simulated flight at M = 0.87, alt = 24,000'

F/A-18 Water-Tunnel Test

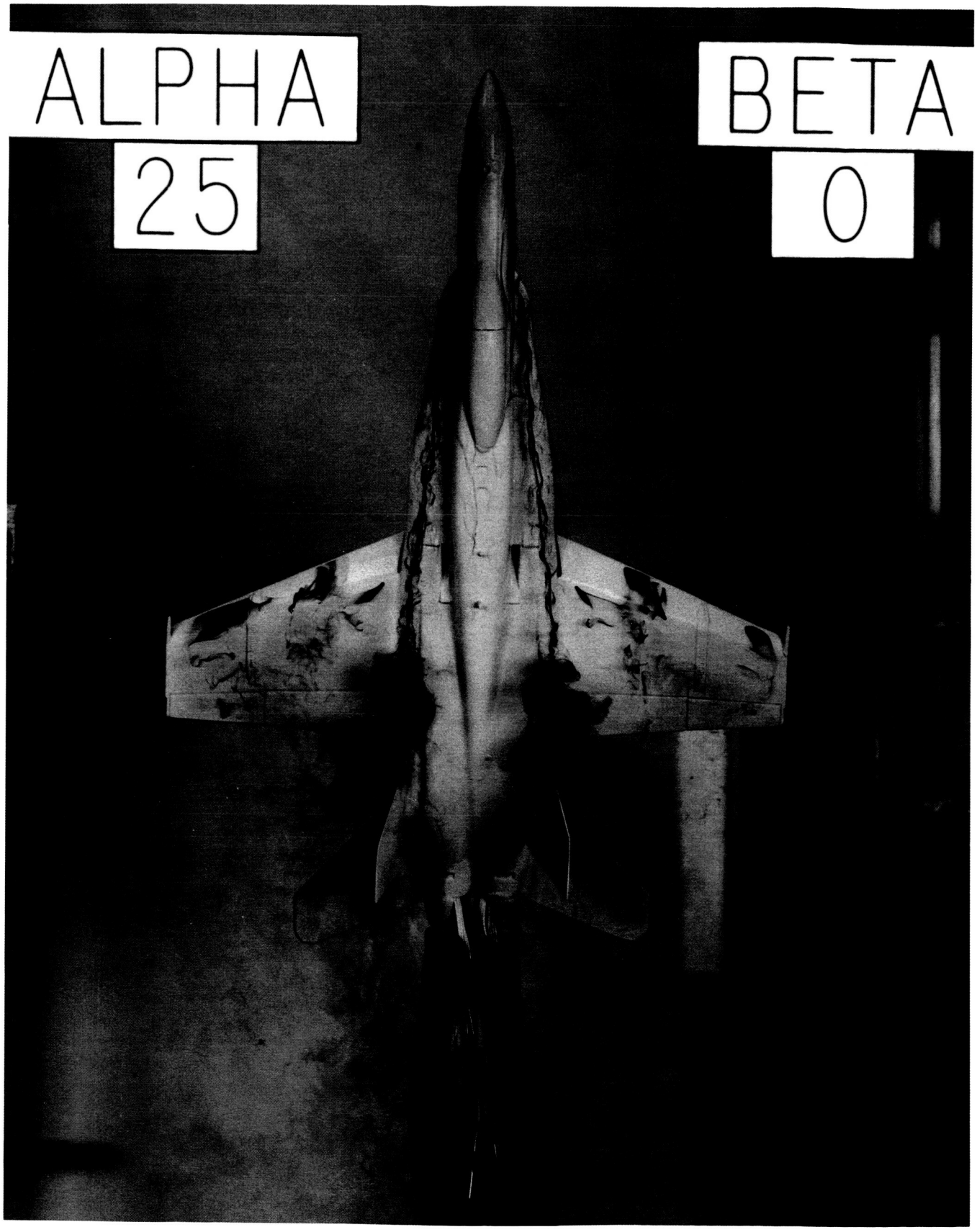
A water-tunnel study on a 1/48-scale F/A-18 model was performed at the Ames-Dryden Flow Visualization Facility. The study was conducted jointly by NASA, the University of Kansas, and Wichita State University under a grant from the Navy. The test was conducted on the F/A-18 to study the flow associated with buffet observed by the twin vertical stabilizers at high angles of attack. The flow associated with the buffet was studied using flow-visualization and hot-film anemometry.

The first figure shows a plan view of the F/A-18 model in the water tunnel (water in the photo flows from top to bottom at 3 in/sec). Colored food dye emanates from several ports in the model surface to provide visualization of the flow. Note the strong leading edge extension (LEX) vortices (vortices are seen on the left and right side of the fuselage) and their respective breakdowns (characterized by an abrupt increase in the vortex core diameter) just forward of the vertical stabilizers. The next two figures are that of a plan and side view of the F/A-18 and the LEX vortex breakdown positions at their respective angles of attack. Data collected correlate well with wind tunnel data of a different sized model and at higher Reynolds numbers.

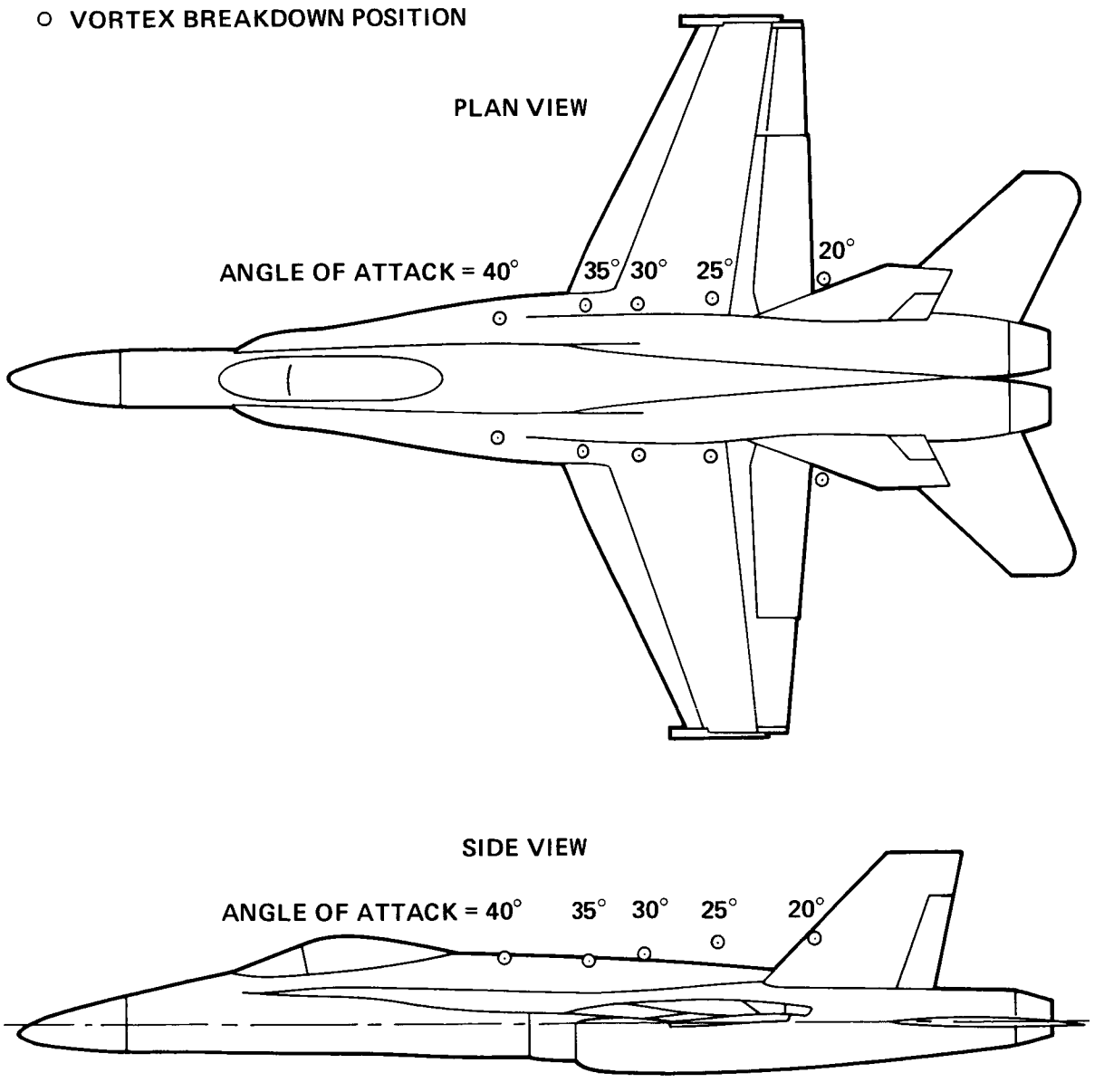
Data from a hot film gage located on the inboard surface of the stabilizer were analyzed in the form of power spectral densities to obtain differences in turbulent energy levels at various angles of attack. Trends show increasing energy content with increasing angle of attack, which correlates well with the LEX vortex breakdown in the flow-visualization data previously noted.

Additionally, dominant frequencies extracted from the power spectral densities, and nondimensionalized through the use of the Strouhal number, remain fairly constant through different flow speeds tested and are nearly the same as those extracted from wind tunnel data of a different sized model and at higher Reynolds numbers.

(J. Del Frate and D. Fisher, Dryden Ext. 3704/3705)



F/A-18 Model in water tunnel at an angle of attack of 25°



F/A-18 leading edge extension vortex breakdown locations with respect to angle of attack

Aeroelastic Control of Oblique Wing Aircraft

The Navy and NASA are currently involved in the design and development of an unsymmetric-skew-wing aircraft capable of 65° wing sweep and flight at Mach 1.6. Such a unique configuration exhibits aeroelastic behavior distinctly different from that of straight, swept-back, or swept-forward wings and has a potential for poor modal response characteristics. The most serious result of such characteristics is flutter (an unstable motion caused by an interaction between structural vibrations and aerodynamic forces). Active suppression of wing flutter can result in substantial weight savings and increases in performance compared with such passive methods as increased structural stiffness and mass balancing.

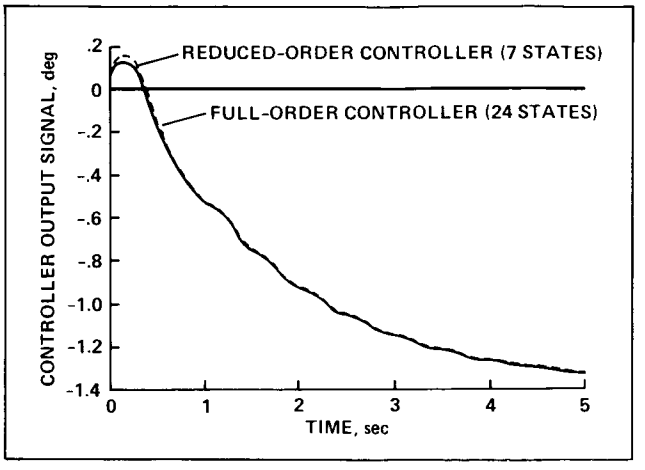
To evaluate the analytical tools required for analyses of oblique-wing configurations, a generic skewed-wing model was developed. The model had a wing skew of 45° and was designed to flutter at Mach 0.70 and 20,000 ft altitude. The model was then used to explore active control synthesis methodologies.

The steps involved in one of the methodologies are as follows: 1) formulation of the state-space model including actuators, a gust model, and an approximation to the unsteady aerodynamics; 2) optimal full-state control law determination; 3) robust output feedback control law formulation; and 5) evaluation of the practical control law.

The design objective was to stabilize the aircraft at a supercritical flutter condition without exceeding position and rate rms activity, and with the additional requirement that the controller be robust. The left and right control surfaces were allowed to operate independently to take advantage of the unsymmetric nature of the aircraft. Robustness of the multiloop control system was evaluated by the singular values of the return difference matrix.

Satisfactory closed-loop stability was obtained for the 24-state full-order controller with all surface activity and robustness requirements met. The reduction process resulted in a 7-state controller while still retaining satisfactory surface and robustness requirements. The figure presents the aileron response of the forward-swept wing to a step-command input. The excellent correlation between the two controllers indicates a practical, active control is implementable for highly unsymmetric configurations.

(G. Gilyard, Dryden Ext. 3724)



Step response comparison of full-order and reduced-order controllers

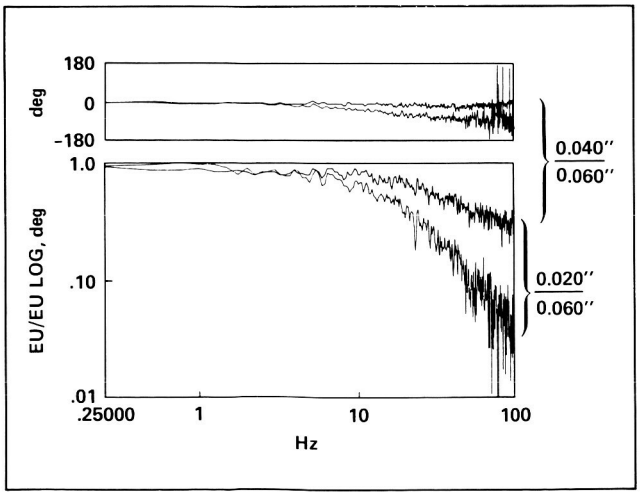
Unsteady-Pressure-Measurement System

Unsteady pressures play a key role in determining the flutter characteristics of flight vehicles. Computer codes exist for use in developing unsteady-pressure predictions in both the subsonic and supersonic flight regimes. These codes are then used in conjunction with an elastic model of the structure to produce flutter predictions. To date, these unsteady pressure codes have been only minimally verified with experimental data at subsonic conditions, with no verification at transonic and supersonic conditions. One of the primary research objectives on the Oblique Wing Research Aircraft (OWRA) program is to develop an unsteady-pressure data base with which to correlate analytical results obtained through flightover the subsonic to supersonic Mach range. In addition, the variable skew capability of the wing permits data collection over a wide range of wing configurations from swept forward, to straight, to swept aft.

Previous attempts to measure unsteady pressures have required the use of individual in situ transducers which proved both expensive and difficult to maintain. Maintenance problems become impossible to solve when the pressure orifice must be located in an inaccessible area.

In order to address the above problem, a pneumatic means of measuring unsteady pressures has been developed for use in the wind tunnel. Full-scale vehicle applications require significantly longer line lengths than models and pneumatic lag and attenuation characteristics could be a significant factor. In support of the OWRA program, a flight experiment was conducted on an F-15 aircraft to evaluate the effects of both tubing (and orifice) diameter and line length. An electronically sensed pressure (ESP) transducer was used as the sensor and the data were recorded at $\geqslant$250 samples/sec Preliminary results shown in the figure illustrate the effect of tubing diameter for a 2-ft line length on both attenuation and lag (phase). Using the 0.060-in. tubing as the reference, both the 0.040- and the 0.020-in. tubing show little attenuation to at least 10 Hz, although the 0.020-in. tubing does attenuate at a much more rapid rate than the 0.040-in. tubing once the break frequency is past. The poorer characteristics of the 0.020-in. tubing are also indicated by its significantly worse phase angle.

(G. Gilyard, Dryden Ext. 3724)

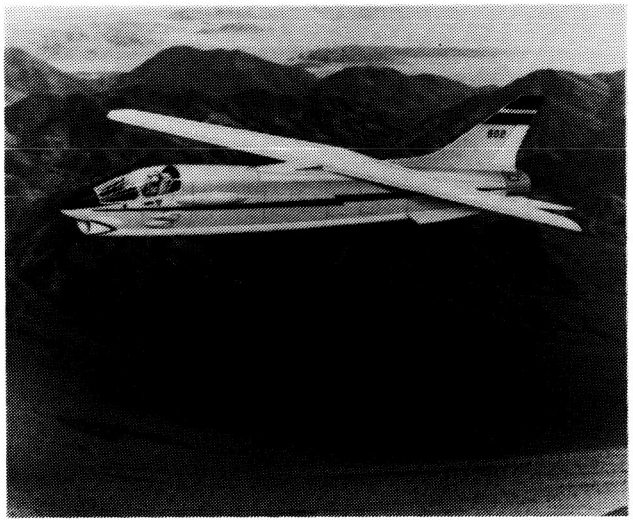


Effect of orifice diameter (2 ft line).

Oblique-Wing Flight Controls

The advantages of oblique-wing airplanes was first noted in the 1940s. However, not until recently have the interest, technology, and mission of an oblique-wing design evolved into a full-scale flight-research program. Theoretical and wind tunnel studies have shown that a variable-sweep oblique wing offers a substantial aerodynamic performance advantage for aircraft missions that require both high efficiency in subsonic flight and supersonic dash or cruise. The disadvantage of the oblique-wing concept is the asymmetry associated with wing-sweep angle. This asymmetry results in significant aerodynamic and inertial cross-coupling between the airplane longitudinal and lateral directional axes.

The test bed for a high-performance oblique-wing research airplane (OWRA) will be the NASA F-8 digital fly-by-wire aircraft (see figure). This aircraft will be modified by the removal of the current high wing and the installation of a composite wing with a pivot assembly.

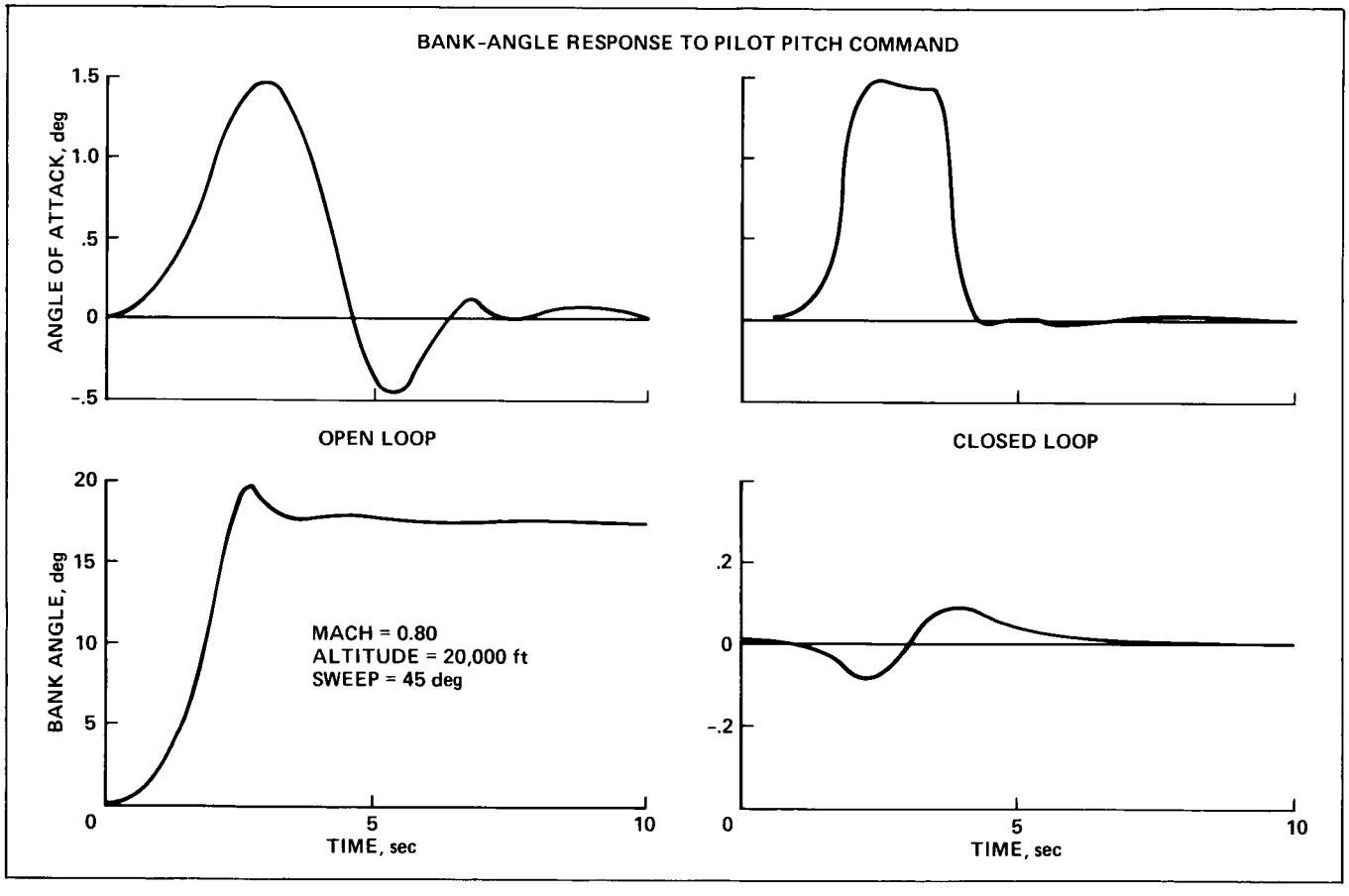


Oblique wing research airplane

The potential advantages of the OWRA can be realized only by the development of related technologies. Foremost among these is the synthesis of a flight-control system which will provide acceptable stabilization and decoupling across the Mach number, angle-of-attack, and wing sweep envelope, while presenting the

flight crew with the feel of a conventional airplane. These stability and decoupling requirements are ideally suited for the application of modern control theory to the solution of these problems. Three candidate control-law development methodologies are being investigated and will be evaluated using ground-based piloted simulation and analysis. Similar levels of decoupling can be achieved by each of the methodologies. Each of the methodologies results in a multiple-in/multiple-output system and uses linear quadratic optimization techniques to design the feedback gains. The effectiveness of one of the control laws in achieving the desired decoupling is illustrated in the second figure. Following piloted simulation and analysis, one of the candidate control laws will be selected for mechanization in airborne computers for evaluation in flight.

(G. Gilyard, Dryden Ext. 3724)



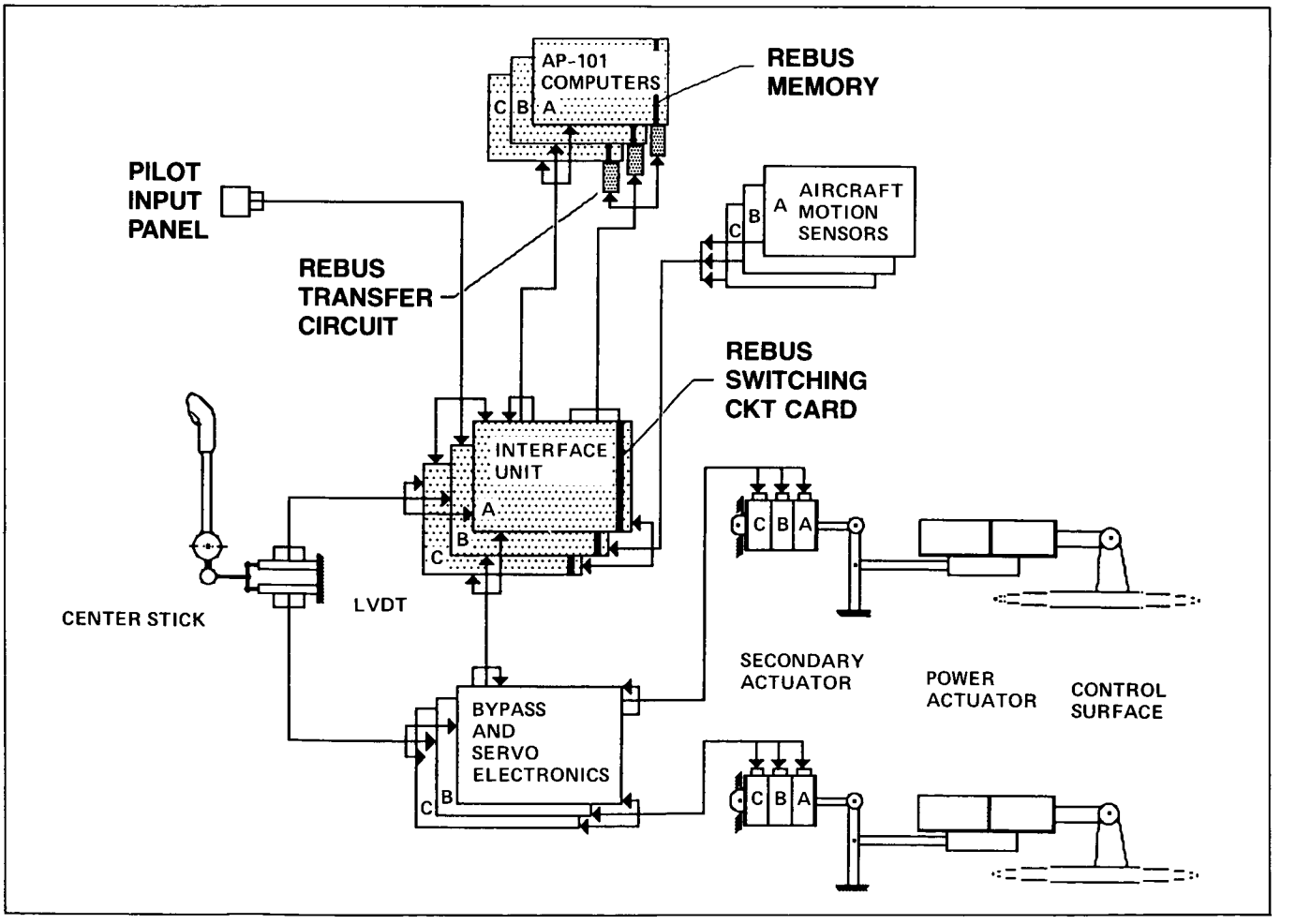
Bank angle response resulting from an angle of attack change of 1.5° at 0.8 Mach number, an altitude of 20,000 ft, and a wing sweep of 45°.

Resident Backup Software

Present flight-critical digital-systems designers protect against the "generic" software error by providing a dissimilar hardware backup system. This approach adds additional cost and complexity to the design. A new fault-tolerant software concept, called "REBUS" for resident back-up software, employing the primary digital computers as host for the backup software portion, has been implemented and flight-tested in the Ames-Dryden Flight Research Facility F-8 digital fly-by-wire airplane. The system was implemented in such a way that essentially no transients occurred in transferring from primary to backup software, even during maneuvering flight. The primary digital-flight-control system was frame-synchronized, while the backup software was run asynchronously for this flight experiment. The REBUS system was designed and implemented under contract with the Charles Stark Draper Laboratory.

A similar backup software concept (called BUCS) has been implemented in the digital-flight-control system that will be flown in the NASA Rotor Systems Research Aircraft (RSRA) X-Wing. The F-16 C&D aircraft being outfitted with digital flight-control systems will also have a similar digital software backup implementation.

(W. Lock, Dryden Ext. 3432)



Simplified F8DFBW REBUS control system schematic

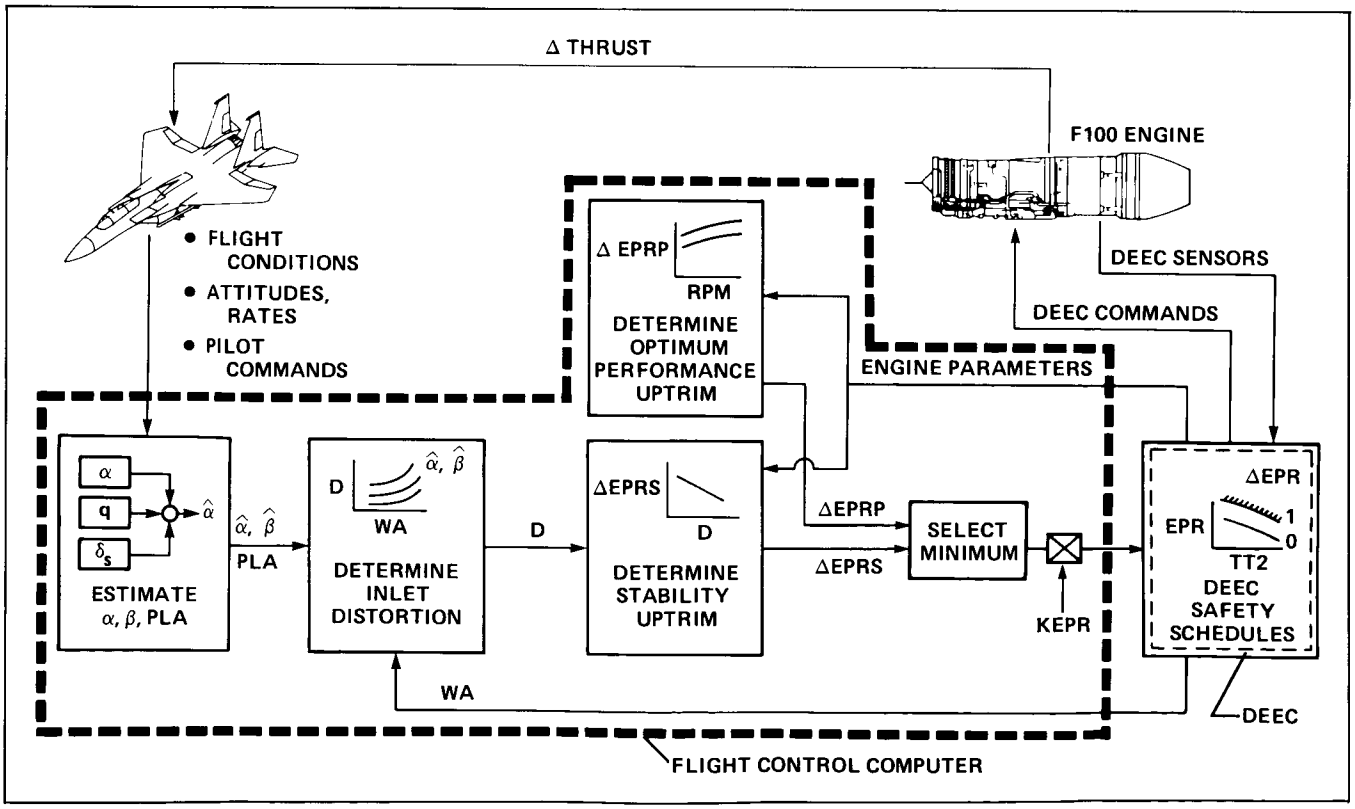
HIDEC Adaptive Engine Control System Evaluation

Substantial performance gains can be obtained by integrating flight and propulsion control systems. Independent optimization of each control system is usually compromised by worst-case assumptions of other systems. This integration is being done under the highly integrated digital electronic control (HIDEC) program.

In a conventional control system, the engine stall margin is large enough to accommodate the worst-case combination of engine- and airplane-induced disturbances. In the adaptive engine-control system (ADECS) mode, the stall margin is modulated in real time based on the current requirements. This permits the unneeded stall margin to be traded for increased engine performance, in terms of increased thrust, reduced fuel flow, or lower operating temperatures. The stall-margin trade on the engine is implemented by uptrimming the engine pressure ratio (EPR).

An evaluation of the ADECS mode was conducted at the Ames-Dryden Flight Research Facility on an F-15 airplane. A digital electronic engine control (DEEC) was installed on one of the F100 engine model derivative engines in the airplane. A digital electronic flight control system, which contains the ADECS logic, is also installed on the airplane. The various digital systems on the airplane communicate with each other through a digital data interface and bus controller.

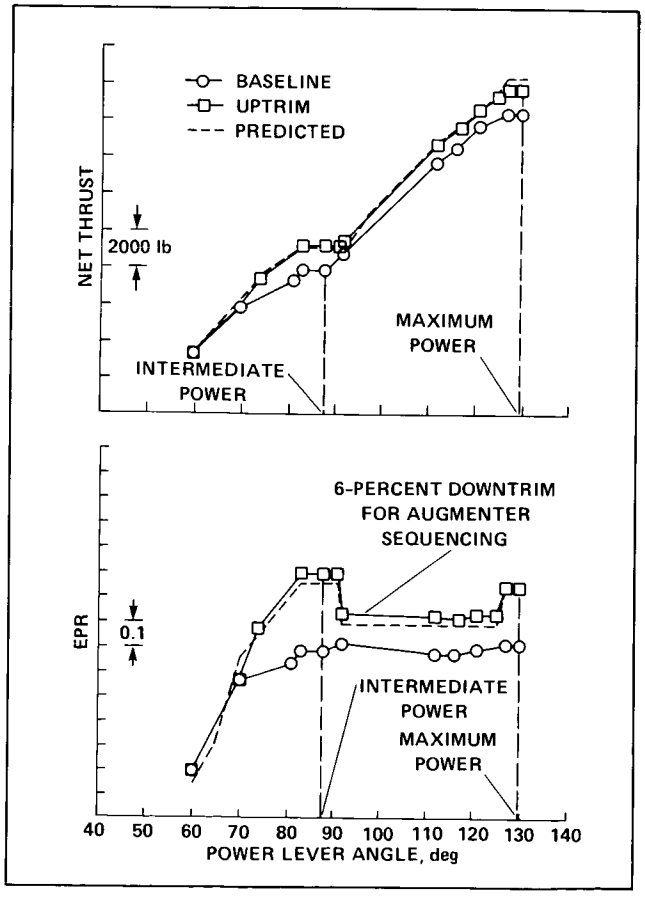
An ADECS diagram in the first figure, show the airplane data being used to estimate the angle of attack and sideslip and throttle angle (PLA). This information, along with the engine airflow, allows the inlet distortion to be calculated, and then provides the amount of stability uptrim (EPRS) available. Another calculation uses engine parameters to determine the amount of uptrim for optimum performance (EPRP). The lower of the two EPR uptrim commands, with a pilot-selectable multiplier (KEPR), is then sent to the DEEC, which implements the uptrim on the engine. The DEEC also contains an upper limit of allowable uptrim for safety.



HIDEC adaptive engine control system mode

The second figure shows ground-run data in which the engine thrust was measured by a load cell. Thrust increases of 1500 lb are shown at intermediate and maximum power for a 7% uptrim. The agreement between predicted and measured data is good.

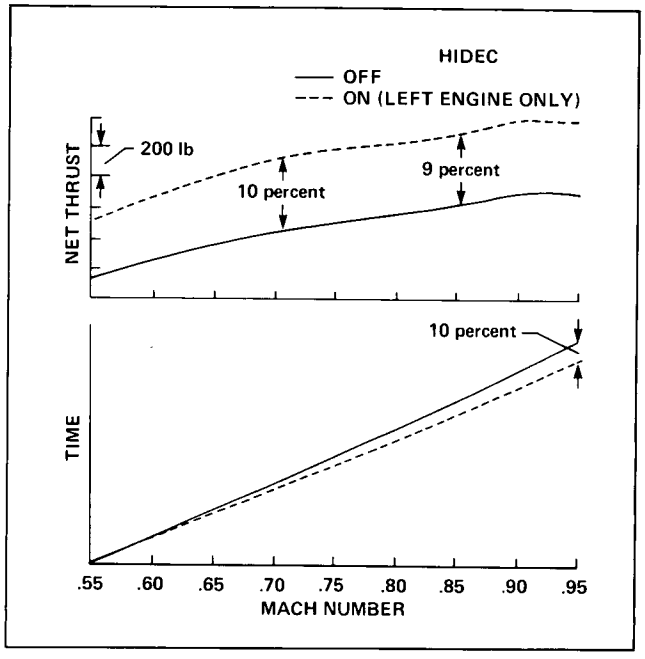
The ADECS uptrim logic was successfully demonstrated in flight tests over the F-15 flight envelope. The ADECS logic successfully accommodated extreme airplane maneuvers and rapid throttle transients. Intentional stalls were generated by increasing KEPR to high values to permit the methodology used in the stall-margin calculations to be validated. Thrust increases were substantial and a typical level acceleration (see third figure), shows the thrust increase and the corresponding 10% improvement in airplane acceleration at 30,000 ft. The fuel consumption was also demonstrated to be lowered significantly (as seen in the fourth figure), which shows a 14% fuel savings at Mach 0.9, at 30,000 ft.



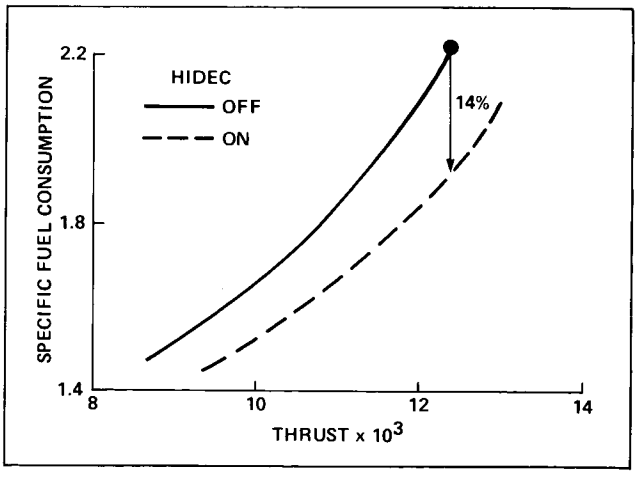
Comparison of measured and predicted EPR and thrust

The HIDEC system holds great promise for future high-performance airplanes. These advanced designs will all have digital flight and engine control systems and data busses linking the systems together, and the ADECS mode can be implemented at essentially no cost or weight penalty.

(L. Myers, Dryden Ext. 3698)



HIDEC intermediate power level acceleration 30,000 ft, 36,000-lb gross weight



Mach = 0.9, 30,000 ft, afterburning power

X-29/F404 Engine Calibration

One of the most important objectives in any performance flight-test program is the measure of thrust. This is particularly true of the X-29 because, by design, it will demonstrate improved performance owing to technical advancements such as swept-forward, supercritical, thin wings, close-coupled canards and a 35% negative stability margin. At stabilized flight conditions, engine thrust equals aircraft drag.

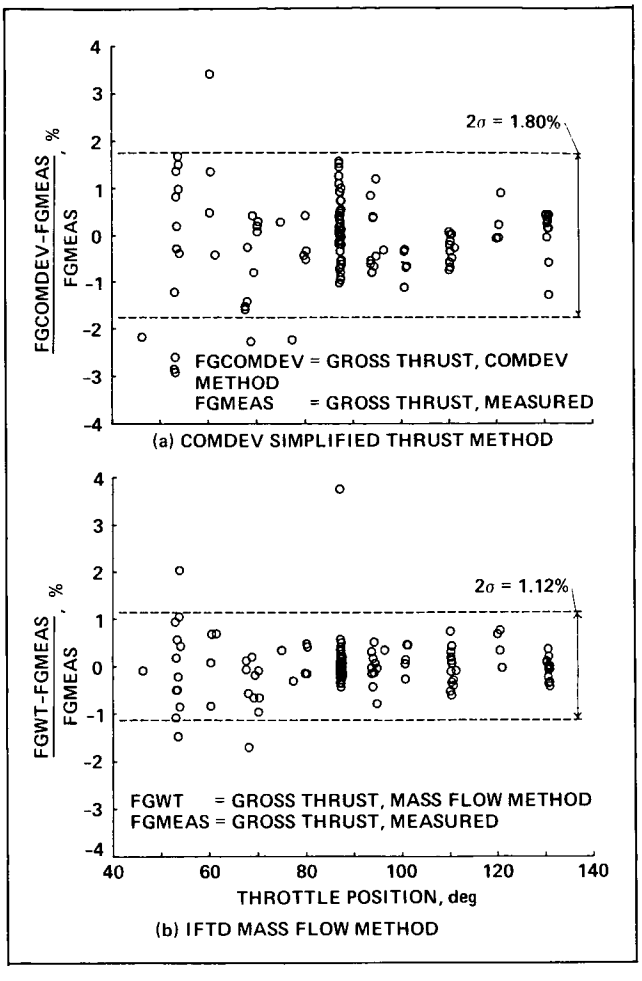
In support of performance tests of the X-29 at the Ames-Dryden Flight Research Facility, a General Electric F404 turbofan engine was calibrated for thrust and airflow at the Lewis Research Center's Propulsion System Laboratory. The objectives of this calibration test were to tailor the manufacturers in-flight thrust deck (IFTD) to accurately calculate thrust and implement an independent, simplified, thrust-calculation technique for real-time evaluation.

Calibration of the IFTD involved correlating calculated and measured values of thrust and airflow, which required an understanding of what influenced the error in the IFTD and correcting for that influence. Two gas-generator thrust-calculation methods are used in the IFTD; one is sensitive to nozzle area and pressure, the other is sensitive to engine total mass flow and temperature. Both methods were calibrated independently.

The Computing Device Corporation's (COMDEV) method of calculating gross thrust has advantages over the more complex IFTD in that it requires much less instrumentation and the algorithm is very simple. Because of computing requirements, the COMDEV simplified thrust method was chosen for real-time in-flight thrust monitoring of the X-29.

Results of the F404 engine calibration show excellent agreement between the corrected IFTD and measured values of thrust. The results also indicate the COMDEV method for calculating thrust gives reasonable accuracies when compared to the more complex IFTD.

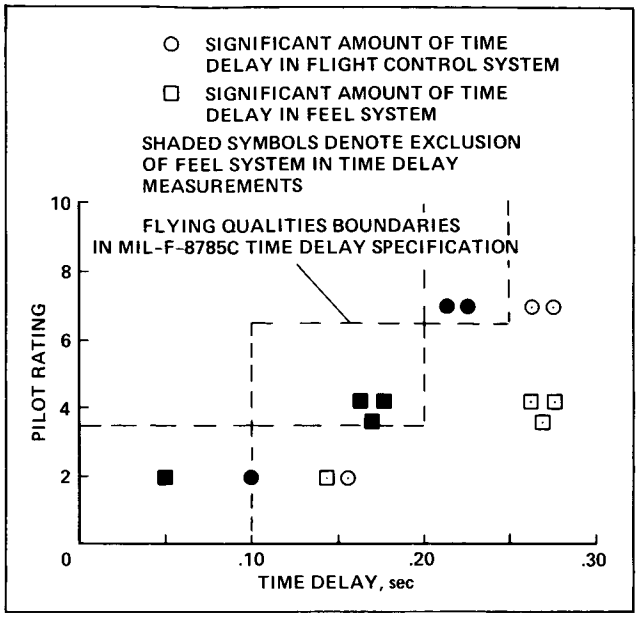
(R. Ray, Dryden Ext. 3687)



Results of the F404 engine calibration showing percent difference between measured and calculated thrust

Effect of Time Delay on Flying Qualities: An Update

Flying qualities problems of modern, full-authority electronic flight-control systems are most often related to the introduction of additional time delay in aircraft response to a pilot input. These delays can have a significant effect on the flying qualities of the aircraft. Recently, time-delay effects on flying qualities were reexamined in light of recent flight-test experience with aircraft incorporating new technology. Data from the X-29A forward-swept-wing demonstrator, a related preliminary in-flight experiment, and other flight observations raised some questions about the validity or at least, completeness of the latest military flying



Pilot rating/time-delay results

qualities specification (MIL-F-8785C) on allowable control-system time delay. These data indicate that the allowable time delay appears to be a function of the shape of the initial aircraft response after the time delay.

One element identified as playing a major role in determing allowable time delay is the cockpit feel system. The feel system includes the spring, mass, and damper characteristics of the control stick that translate the pilot's stick-force input into stick position. In a modern flight-control system, the feel system provides the "artificial feel" necessary for the pilot to maintain adequate stick force and position feedback. This study identified the feel system as a unique dynamic element in the overall flight-control system. Data indicate that when a significant amount of the overall time delay resides in the feel system, the predicted degradation (in the form of poor pilot ratings) in aircraft flying qualities do not surface. These degradations were evident when a significant amount of the overall time delay was placed in the flight-control system, downstream of the pilot. In addition, these data indicate that excluding feel-system dynamics from time-delay measurements provide better correlation with the allowable time-delay specifications.

As a result, two aspects of feel-system effects on flying qualities were investigated. The first considered the feel system as another filter in the flight-control system which can significantly affect the shape of the initial response of the aircraft following the time delay. The second considered the feel system as a unique dynamic element whose time-delay contribution can potentially be discounted by the pilot since he or she has direct access to both the input force and output stick displacement of the element. The results of this study supported both aspects.

These initial findings have resulted in an effort to explore the relationship between feel-system dynamics, allowable time delay, and initial response of fighter aircraft. An in-flight simulation program on the USAF/AFWAL NT-33 variable stability aircraft will be conducted in 1987 to provide additional data for the allowable time delay specifications and further insight into pilot-modeling identification.

(R. Smith and S. Sarrafian, Dryden Ext. 3730)

F-14A Variable-Sweep Transition-Flight Experiment (VSTFE)

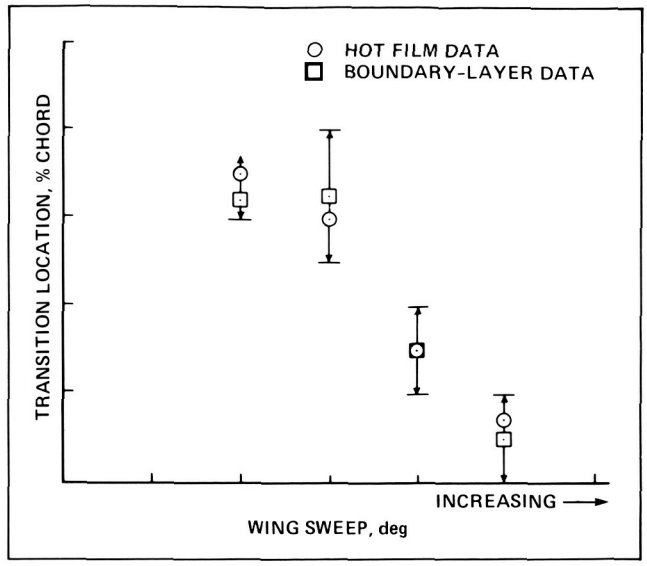
The F-14A Variable-Sweep Transition Flight Experiment (VSTFE) is a cooperative Langley and Ames-Dryden effort to investigate the effect of several natural laminar-flow cambers on boundary-layer transition. The objectives of the experiment are to 1) validate the pressure distributions of three wing airfoil shapes using wing-surface-pressure measurements at the design flight conditions and at several other flight conditions; 2) analytically determine transition location and disturbance frequencies from flight-measured boundary-layer rake, surface pressure, and acoustic measurements; 3) compare transition location values determined using the techniques of objective 2 and assess the strengths of each technique; 4) validate analytical techniques for determining transition location using experimentally derived values; 5) develop techniques for measuring disturbance frequencies in flight; and 6) visually determine the transition and shock location using flow-visualization techniques.

Three gloves are to be flight tested. Glove 1 is a "clean-up" of the existing F-14A airfoil shape; gloves 2 and 3 are modified airfoil shapes specifically designed (one each by Langley and Boeing) to achieve laminar flow.

Boundary-layer, surface pitot tube, flush static pressure orifice, thin-film gage and acoustic measurements are currently being obtained for glove 1, which is located on the left wing of an F-14A aircraft (see figure). The instrumentation is set up as shown in the second figure.

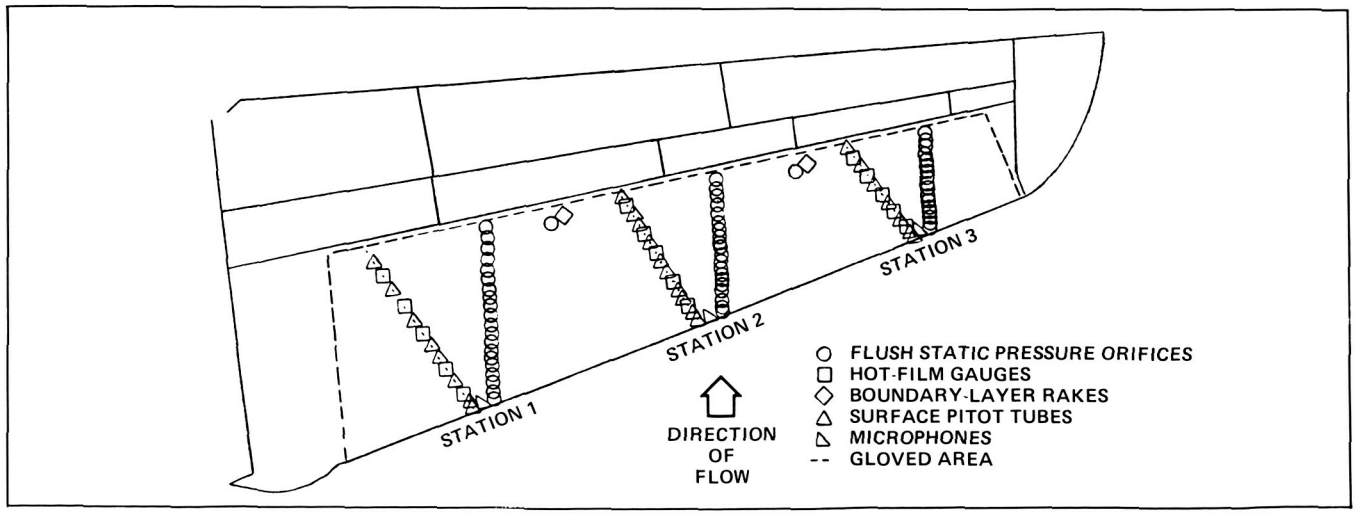
Typical results are shown in the third figure. The actual scales have been omitted because data are restricted to U.S. government agencies and their contractors. Preliminary results indicate that a significant amount of laminar flow is obtainable for transport Reynolds numbers at the higher sweep angles. Although gloves 2 and 3 remain to be tested, the data obtained for glove 1 encompass a variety of pressure distributions for a range of sweep angles. The hot-film anemometry system designed to detect laminar-to-turbulent transition location is installed on the glove and results are obtained in real time. The hot-film anemometry system is currenly the primary system used to determine transition location. Flow visualization, along with surface imperfection and degradation studies, is also scheduled to be conducted on glove 1. Upon completion of glove 1 flight testing, gloves 2 and 3 are expected to be fabricated and flight-tested.

F-14A aircraft with VSTFE glove on left wing



Transition location versus wing sweep, station 2

(B. Trujillo and R. Meyer, Jr., Dryden Ext. 3701/3707, and D. Bartlett, Langley Ext. 2045)



Glove 1 instrumentation setup

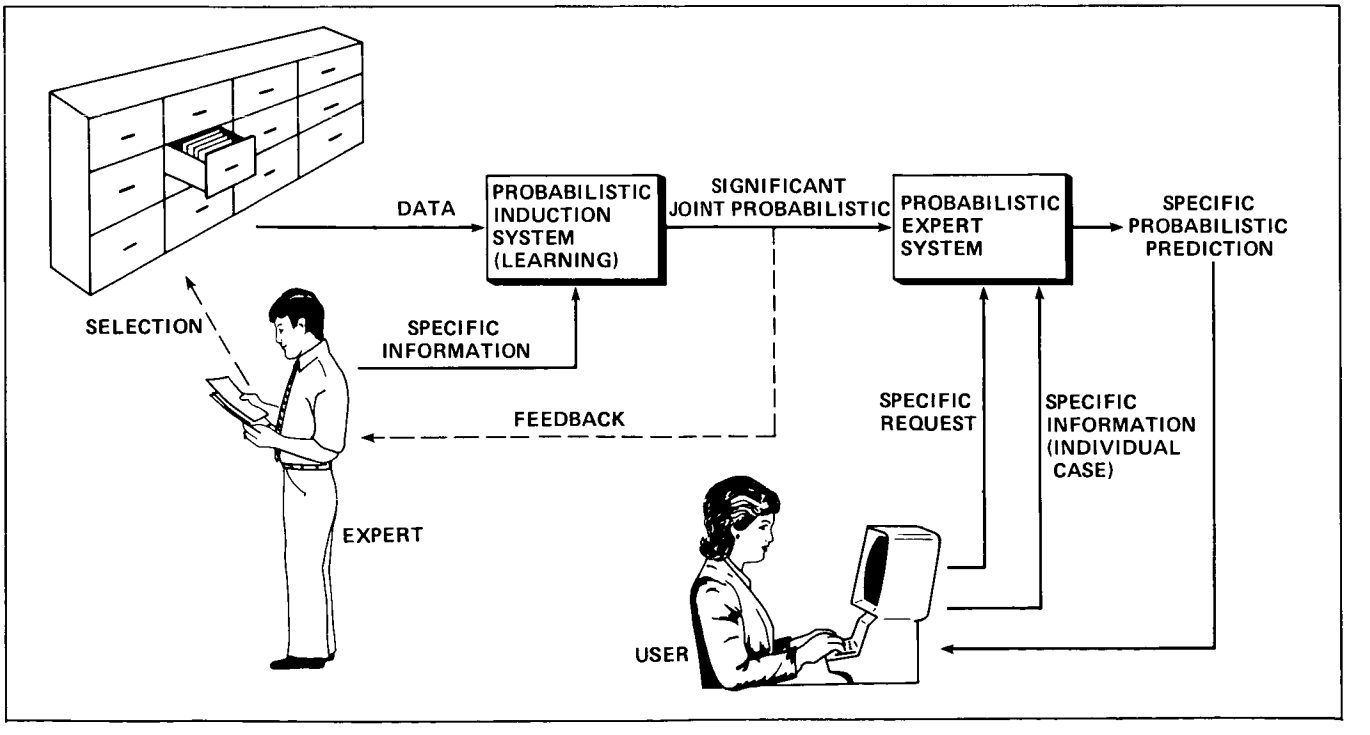
Aerophysics

Probabilistic Expert Systems

During FY 86 a system that learns probabilistic expert systems directly from data was designed and implemented. This system (the induction system) is given a data base (in our case, a medical data base) and searches it for combinations of symptoms/tests that are significantly different from random expectations. These probabilistic patterns (actually, joint probabilities) are stored and can be used to make (probabilistic) predictions. The output from the induction system is the set of all significant joint probabilities which form one of the inputs to the actual probabilistic expert system (see figure). The other input is specific data about an individual. The probabilistic expert system takes both inputs and computes the (conditional) probability of interest. For example, using the test data base, the probabilistic expert system was able to predict which patients were "hyperthyroid" based on various symptoms and the patterns between the symptoms that the induction program discovered.

The probabilistic expert system can predict which pieces of information would be most applicable to a given individual, thus minimizing the amount of testing necessary. This approach exploits what computers are good at – manipulating numbers – and leaves the high-level understanding/interpretation to the expert. The implementation generated many theoretical problems that were solved in an interesting way. For example, statistics has long had difficulties dealing with "missing data." In this implementation, missing data were not assumed to be random – in fact, the medical data base had the highest correlations between missing values. This shows that sometimes what is not known can be as informative as what is known.

(P. Cheeseman, Ext. 6526)



Actual probabilistic expert system

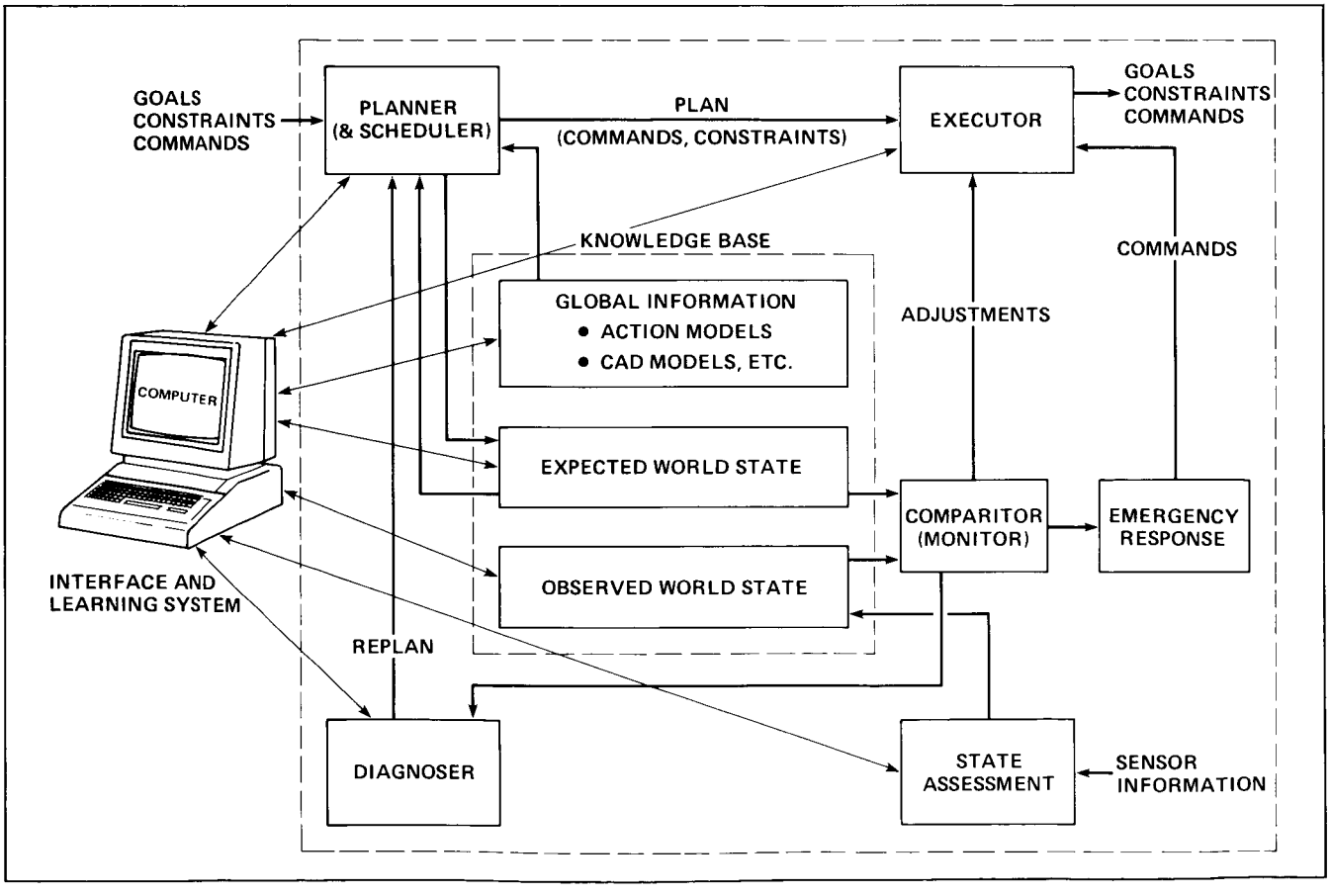
Planning/Scheduling Project

Ames Research Center is continuing a project aimed at providing automatic planning and scheduling capability for a variety of NASA applications. Future versions of this system are intended to be incorporated into both manual and automatic control systems for the Space Station as well as mission control and ground operations. It is expected that the main payoff will be in rapid automatic replanning of missions or mission subtasks caused by unexpected events.

This planner was designed in FY 85/86 as part of the Artificial Intelligence research activity and the Systems Autonomy Demonstration Project (SADP). As a result of numerous discussions of possible applications areas and future requirements, the task of automatic/manual control of the communications officer (INCO) task was selected as meeting these requirements. Using this application, an automatic scheduling system was implemented in PROLOG/LISP on a Symbolics computer that is able to plan communications tasks typically found in INCO. This implementation has many features that make it one of the most advanced planning/scheduling systems in existence.

The main new feature is an explicit representation of all the tasks to be scheduled and their associated conditions in a temporal logic. This makes it possible for the computer to reason about possible locations of activities on a time line (similar to the way it is currently done manually). When the system chooses the slot on the time line for a particular task, it leaves all possible locations open (if the required resources are available) until enough information has accumulated to make a good choice. This "least commitment" approach avoids costly backtracking of poor initial choices and leads to more flexible schedules. Interesting interactions between least commitment of tasks in time and possible resource conflicts have been discovered. Also, a graphical user interface has been developed that shows the assignment of tasks and resources on the time line, as well as indication of possible "slack" in the assignments (for simple schedule adjustment).

(P. Cheeseman, Ext. 6526)



Executive controller planning/scheduling project

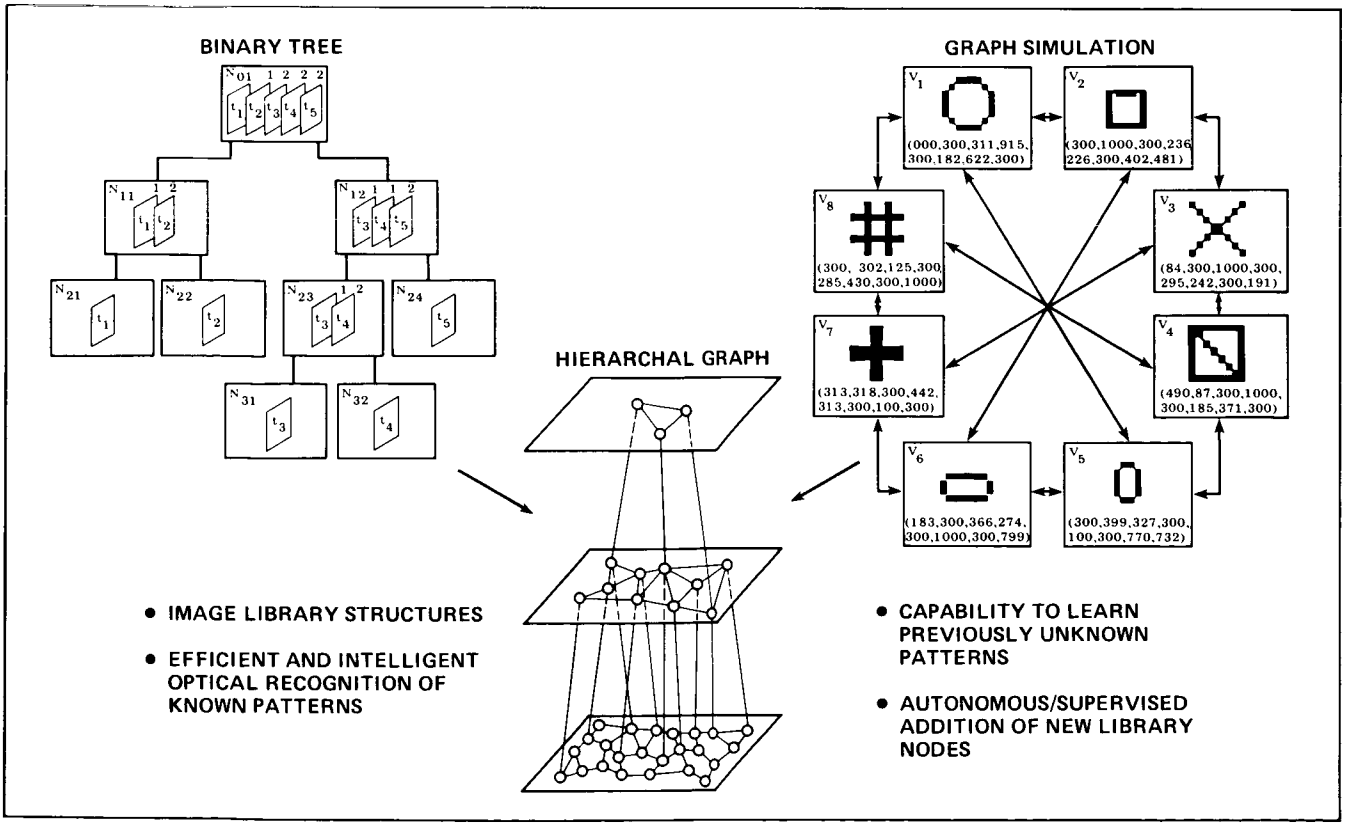
Optical Information Processing

The overall goal of the optical information processing research at Ames Research Center is the incorporation of artificial intelligence methodologies into optical processing systems. This merger of two previously diverse scientific disciplines will allow the development of an intelligent data/scene pattern-recognition capability for Space Station autonomous devices. During the past year, significant progress has been made toward the realization of this capability through the theoretical development and simulation of image library structures for a high-speed multifilter optical correlator.

The manner in which a pattern-recognition system identifies an input image is to scan a library of reference images searching for the highest correlation. A conventional search procedure is to sequentially arrange the reference images, correlating with each in turn. (This approach is akin to looking up a word in a dictionary by reading every word from A to Z; not a particularly efficient or elegant search method.) Three alternative library structures are shown: the binary tree, the multilinked graph, and the hierarchal graph. These library structures allow efficient image identification by intelligently directing the scanning sequence, thereby minimizing the number of steps or correlations required. The hierarchal graph is a synthesis of the tree and the multilinked graph structures that contains the advantageous characteristics of each.

All of the image library structures developed exhibit a learning capability by which a previously unknown image can be recognized on subsequent encounters via the autonomous or human-supervised addition of new library nodes. Learning, as described in this manner, is synonymous with knowledge acquisition. But any sentient being (or machine) not only accrues new facts, but "learns" how to effectively use, reorganize, and make deductions from its existing knowledge base. During 1986 a working system incorporating a tree library structure was developed which recognized known objects within the tree. This system also demonstrated the ability to incorporate unknown objects into the tree under several schemes.

The simulation can construct various types of matched spatial fitters to quickly evaluate these different filter types. For example, the perfor-



Optical information processing

mance of binary filters using synthetic discriminatory functions has been evaluated which shows its usefulness in distortion-invariant pattern recognition.

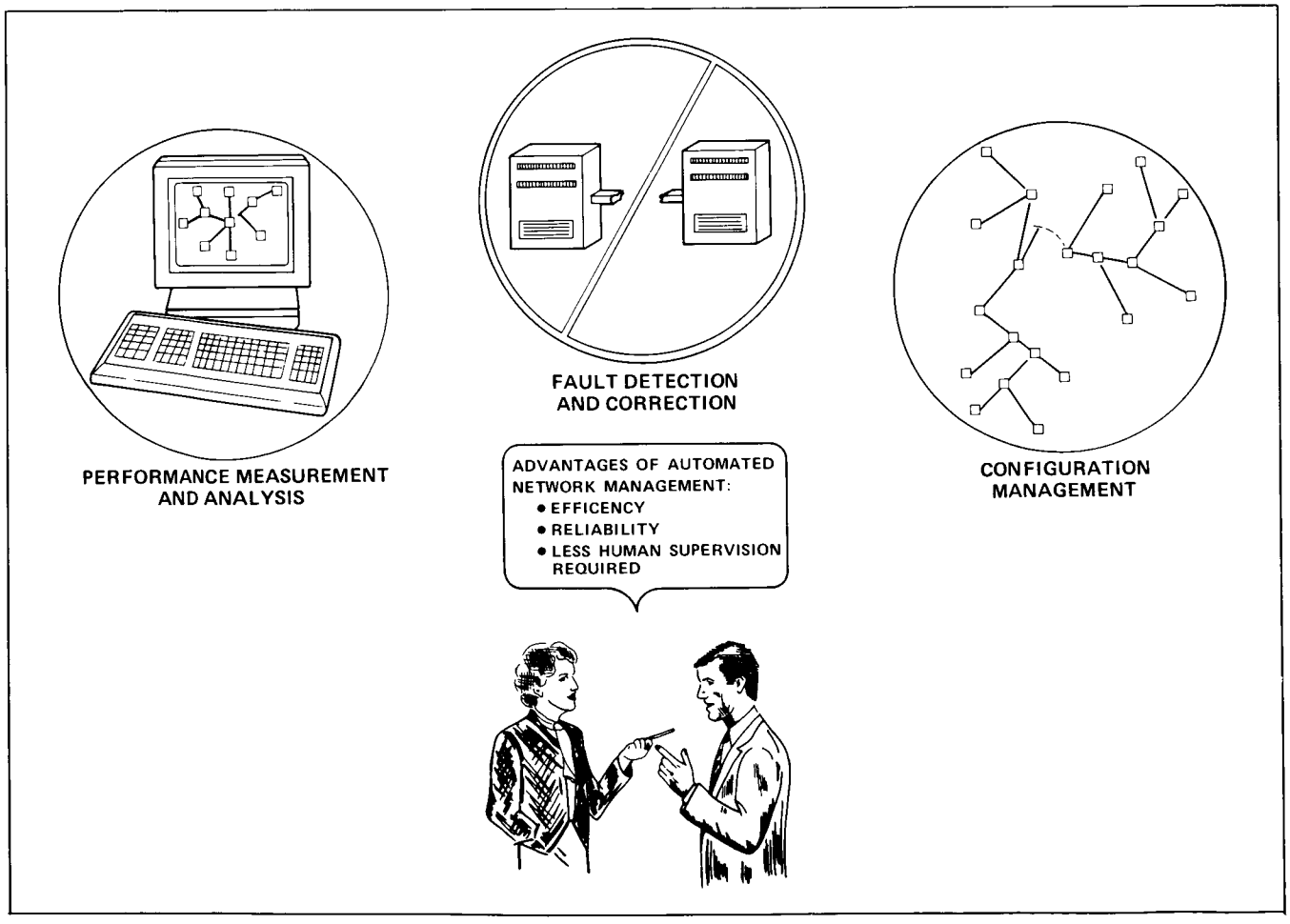
(D. Ennis, Ext. 6525)

Data-Network Management

Management functions are essential for efficient and reliable use of a network. For the Space Station these functions must be highly automated, so that the crew is not burdened with routine maintenance tasks. Monitoring functions include performance measurement, performance analysis, and artificial traffic generation. On-line collection and analysis of statistics about network traffic is the only way to accurately determine the performance of a network. Artificial traffic generation is a tool for determining limitations of the network and planning for its future growth.

The purpose of fault detection and isolation functions is to ensure that failure of any device attached to the network will not cause failure of the entire network, but only to the function or service offered by that individual device. When a problem is detected, the network should be able to determine the nature of the problem and to isolate the fault to a single component or to a small group of components. The network should then be able to automatically reconfigure itself to bypass the failed component. Configuration functions include physical management of stations, such as address management and setting of station parameters, and network reconfiguration.

The scope of network-management functions must be broader for the Space Station local-area network than for land-based networks. Because of the uniqueness of the Space Station environment, NASA cannot depend on industry to develop network-management facilities that will suffice for Space Station use. Our study of network management for the Space Station includes an analy-



Data-network management

sis to determine what network-management functions are necessary, and network simulation and emulation to study possible implementations of these functions and to determine the resulting impact on network performance.

(M. Johnson, Ext. 6525)

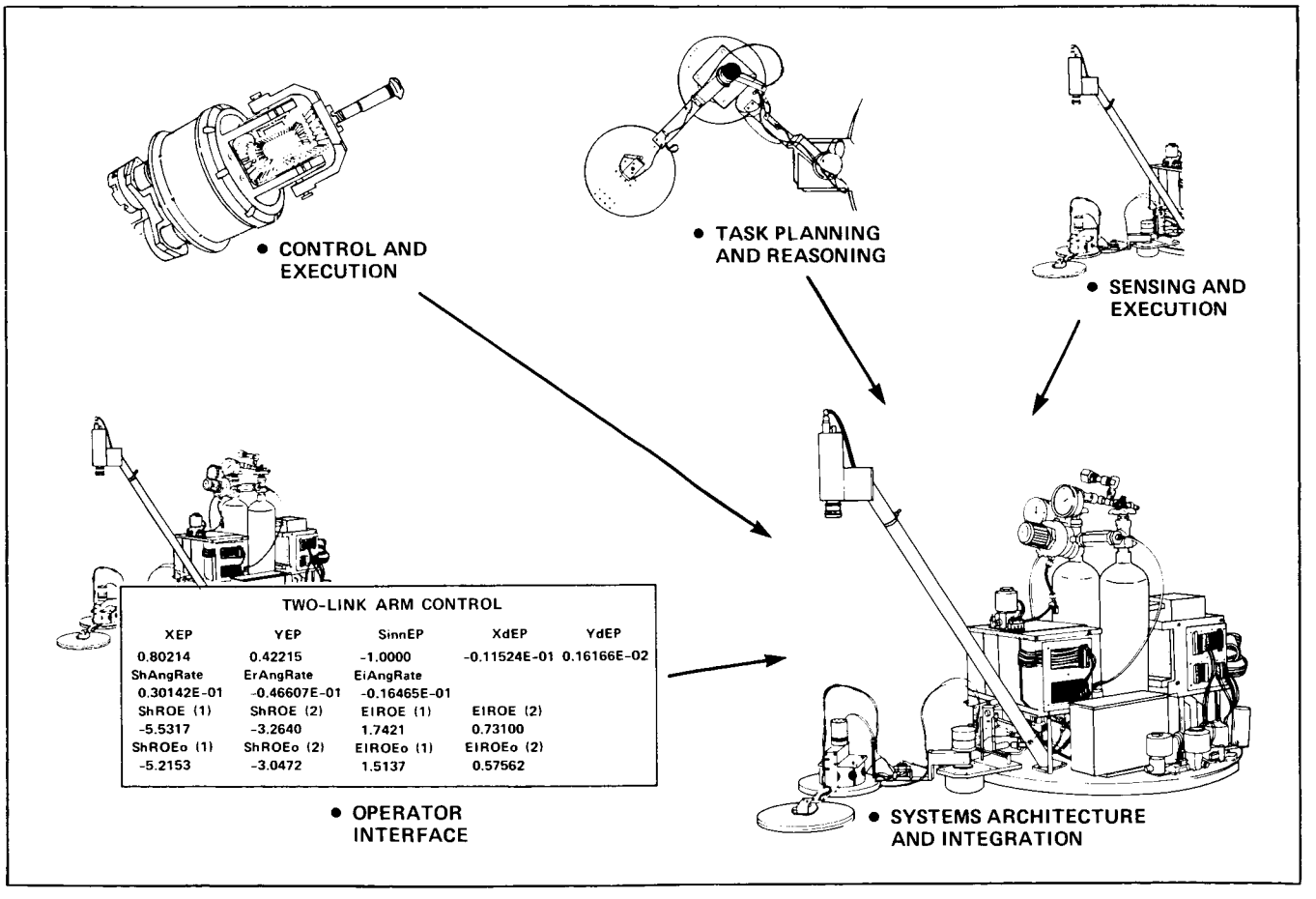
Mobile Intelligent Robots for Satellite Servicing

A laboratory robot designed to perform satellite servicing tasks in space has been developed by the Ames Research Center/Stanford Department of Aeronautics and Astronautics cooperative research team. The current robot consists of an "arm," complete with an "elbow" joint attached to the mobile base by a "shoulder." The mobile base is equipped with a vision system, a command-control-communications system, and a propulsion system. The base and arm float on a cushion of compressed nitrogen gas which simulates a space environment.

The technologies involved in the mobile intelligent robot consist of the following elements: sensing and perception, task planning and reasoning, control and execution, operator interfaces, and system architecture and integration. A microprocessor housed within the base controls the movement of the robot; images received from a small camera positioned on the robot provide positional information; and the planning system provides control information to the propulsion system to allow tracking relative to the target instead of the base. Currently, the operator controls the robot via commands transmitted through a telemetry link.

The mobile intelligent robot serves as an excellent test bed for rapid prototyping and evaluating intelligent systems technologies in a simulated space environment at very low cost.

(H. Lum, Ext. 6544)

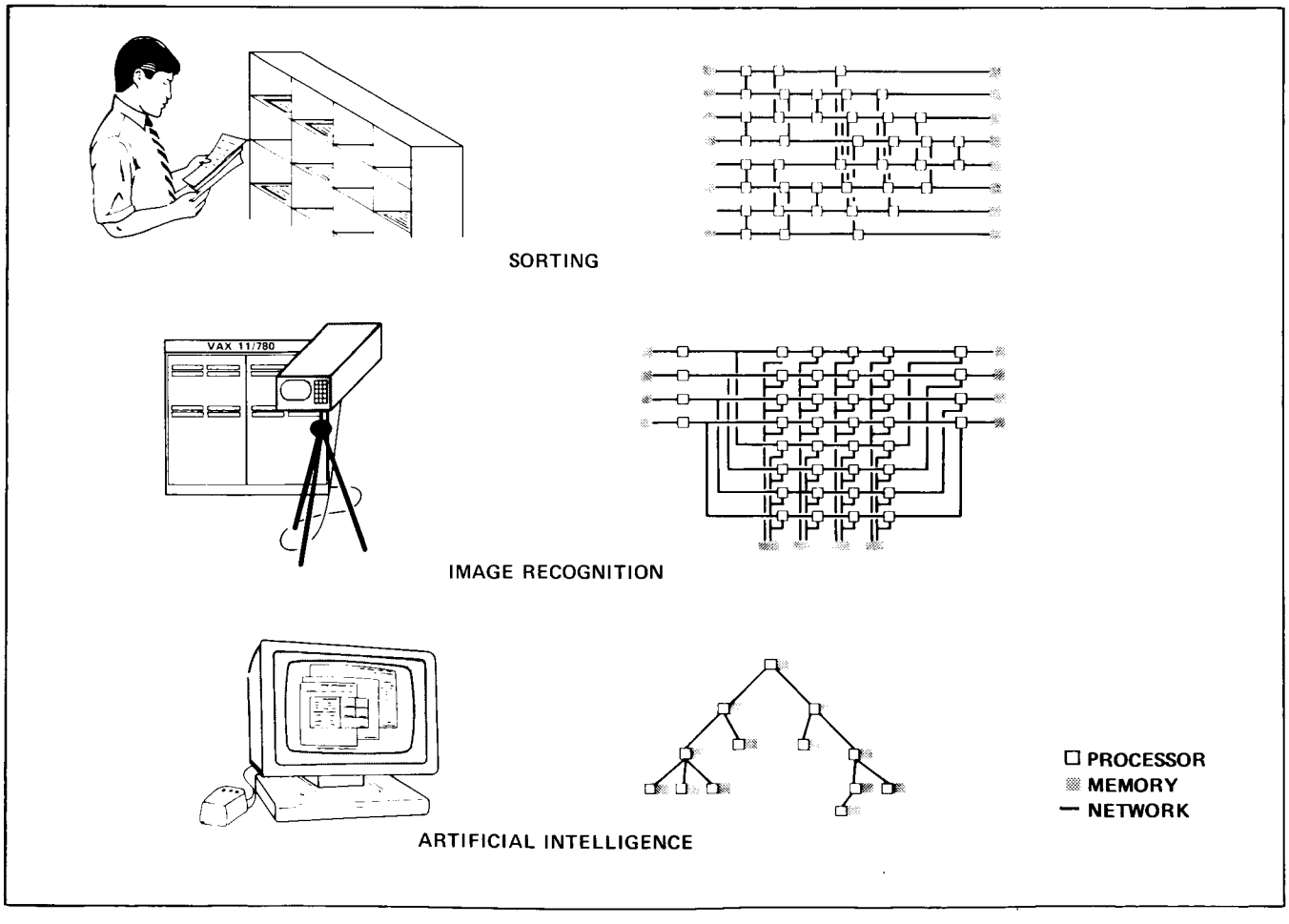


Mobile intelligent robots for satellite servicing tasks

Parallel Processing Dynamic Reconfigurability

To meet the computing demands of the next decade without prohibitive software-development costs, dynamically reconfigurable hardware and operating systems are a must. Fundamental physical limitations and the ever-increasing demand for computing power force us toward parallel processors with thousands of processing elements. New techniques must be developed to program these parallel processors without incurring a like increase in software cost. Ames Research Center has examined the characteristics of hardware and software whose performance parameters (such as speed) can be increased without limit by adding components and proposes the development of such a system with no central controller, single operating system, or other single critical component. The operating system and application software and hardware are all dynamically reconfigured hierarchies ultimately built from simple replicated atomic components. Self-replicating codes will be used, supporting self-checking for consistency and accuracy at all stages of development.

The anticipated programming tasks of the next decade cover a wide range of applications and structures, but only a few algorithm classes are supported on today's machines. Sorting, a typical task, involves little processing, moderate memory, and a large volume of communication, which is not easily described by any regular pattern (though it can be completely determined before execution begins). Sorting is difficult on current supercomputers because they derive their speed from mapping totally regular algorithms onto a dense processor set surrounded by a large collection of memory. These machines support algorithms, such as nonadaptive image processing, that involve large volumes of predetermined processing, with little communication. Artificial intelligence is rapidly dominating, but it has



Parallel processing dynamic reconfigurability

neither a regular architecture nor a predeterminable structure.

During FY 86, a simulation of such a dynamically reconfigured machine and operating system was written and executed on a Symbolics LISP machine. The simulation used the first distributed operating system on a parallel processor; this was the first machine without a central controller. The simulation revealed that processor utilizations of 26% (application) and 13% (overhead) were achievable, and it is estimated that 13% (application) utilization should be typical. This compares with standard vector processors that seldom are utilized above 10%.

(R. Meier, Ext. 6526)

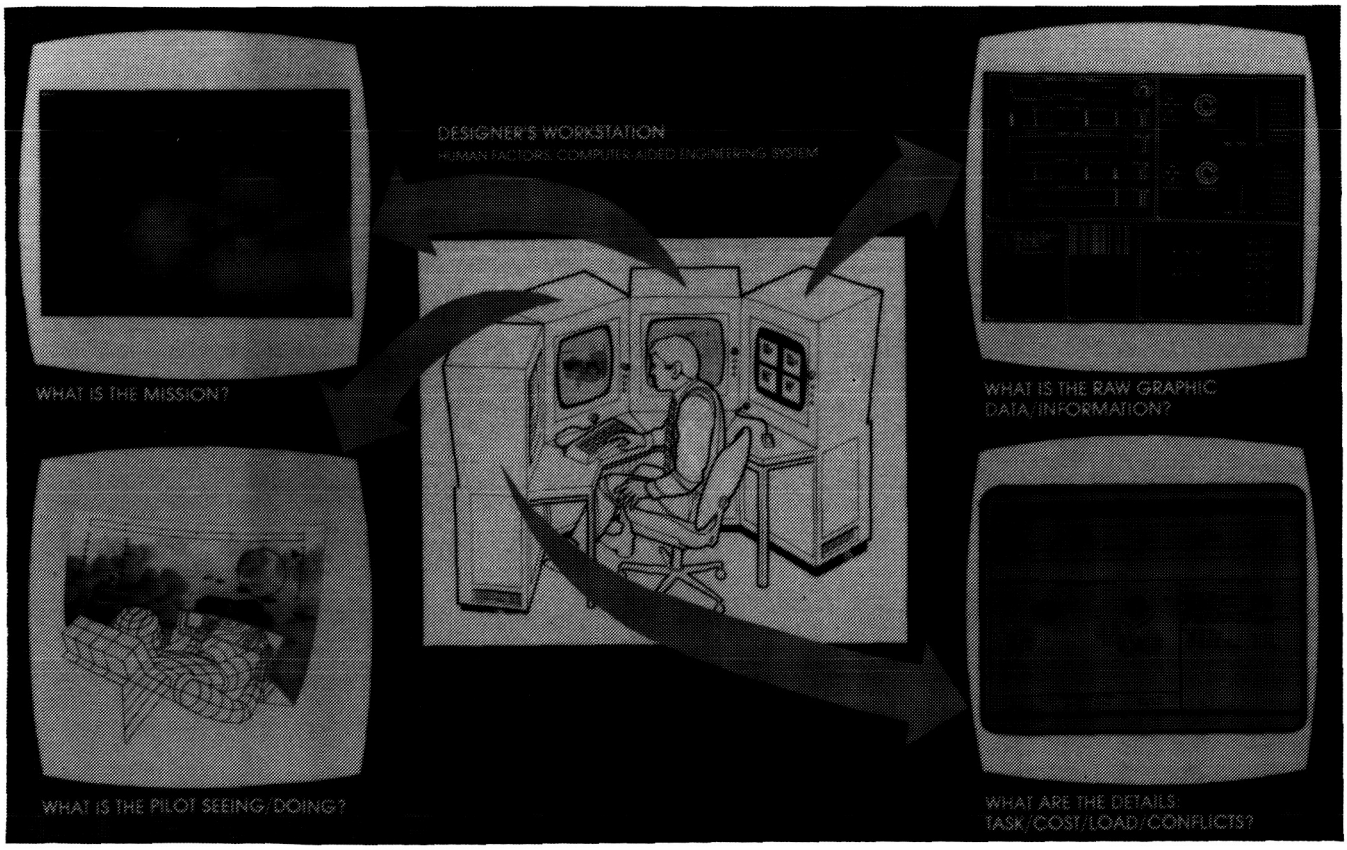
Expert-System Development in Support of Army-NASA Aircrew/ Aircraft Integration

An Army-NASA exploratory development program, A^3I, has the purpose of developing a rational predictive methodology for helicopter-system design, including mission requirements and training-system implications, that integrates human-factors engineering with other vehicle/system design disciplines at an early state in the development process. The program will produce a prototype human-factors computer-aided-engineering (HF/CAE) workstation.

A system has been developed by the Information Services Office (ISO) that considers the effect of a particular cockpit design or mission specification on pilot performance. The influence of training can be estimated for use in the pilot performance and behavior models system.

In June a demonstration of the A^3I designer's workstation marked a major program milestone. A helicopter-ambush mission was simulated. The main thrust of the ISO's demonstrated accomplishments was to elucidate certain aspects of the pilot model to make them more accessible to adjustment according to pilot-training level. Specifically, ISO has done the following:

1. Identified such pilot-model features as the visual, auditory, cognitive and psychomotor (VACP) workload factors and the time needed to complete certain activities, and used these features to establish a pilot-profile module.



Army-NASA aircrew-aircraft integration program (A^3I)

2. Developed procedures to record the skills that the pilot applies to perform a mission.

3. Identified occasions when the VACP limit is exceeded and the activities contributing to such overload.

4. Enabled the pilot profile to affect the way certain activities are executed.

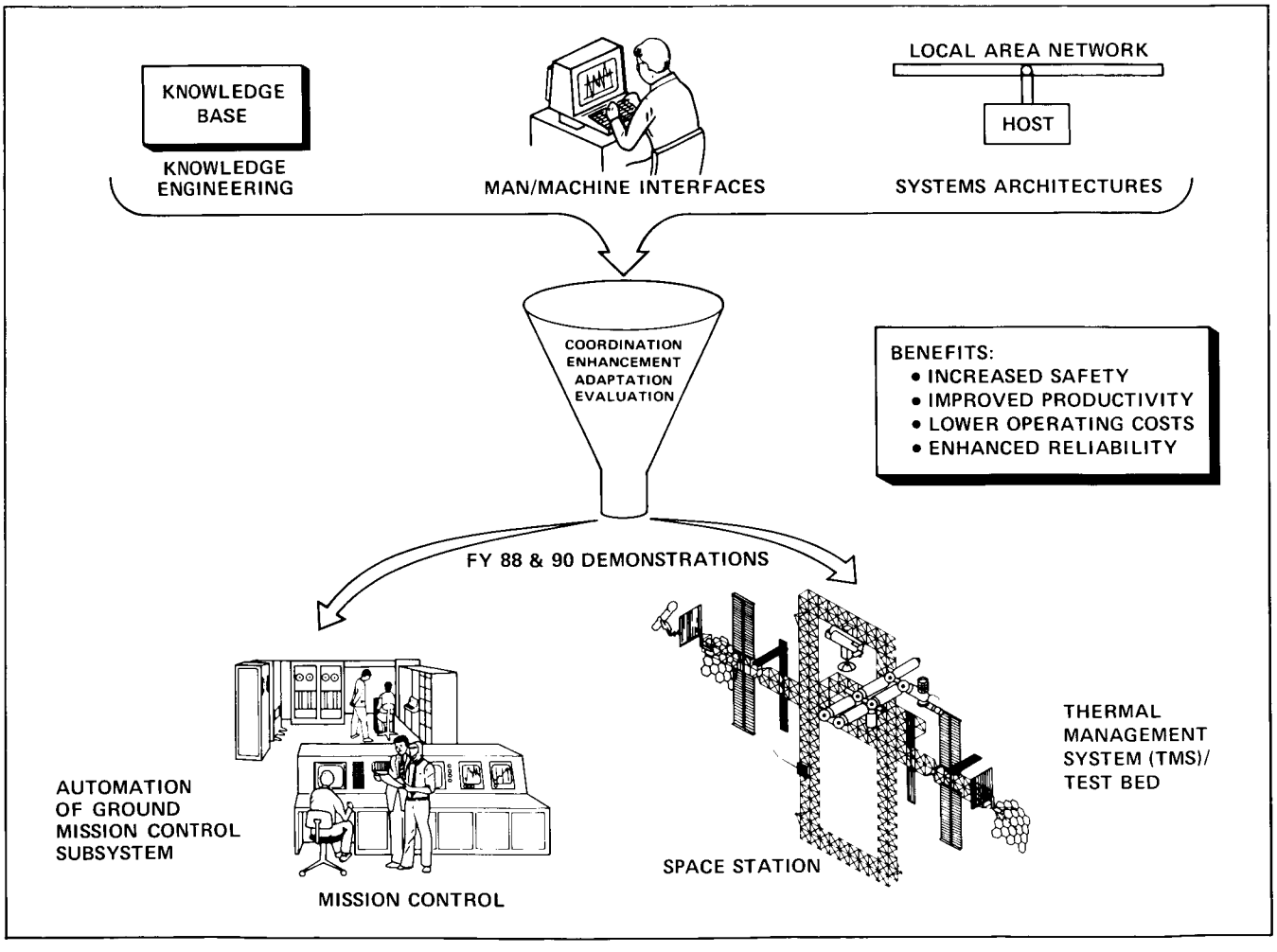
The user can now easily access the pilot profile and make adjustments according to two training levels and assess in detail the cumulative effects on mission performance of profile differences attributable to training.

(P. Nachtsheim, Ext. 6526)

Systems Autonomy Demonstration Program

Research from universities and research centers has hinted at the value of artificial intelligence (AI) technologies for NASA's programs. However, these technologies are still relatively untried in the context of automated space systems monitoring and control. Ames Research Center is providing a lead-center role in the development of AI technologies within NASA, and as a part of this effort is coordinating the Systems Autonomy Demonstration Program (SADP) in recognition of the need to develop, validate, and demonstrate these technologies for transfer into operational real-time space systems.

The program, which will perform technology demonstrations through joint endeavors between ARC and NASA operational centers through FY 96, is focusing on the initial two demonstrations for FY 88 and 90. The program will advance, support, and exploit knowledge engineering technologies, human/machine interfaces, and systems architectures from industry, academia, and other government entities. Functions under evaluation for automation include monitor-



Systems autonomy demonstration program (SADP)

ing and control; automatic fault recognition, diagnosis, and reconfiguration; and scheduling and planning. Potential applications include both ground-based systems such as mission control, and on-board operations such as on the planned Space Station.

Work so far has included the development of a program plan, coordinating the participation of various groups both here at Ames Research Center and at other NASA centers, the selection of a demonstration site and problem area for the FY 88 demonstration, the start of development of a project plan and functional requirements definition for the 1988 demo, and the development of a preliminary research rapid prototype.

The selected demonstration site is the Johnson Space Center, utilizing the Space Station thermal management system (TMS) test bed. This demonstration was selected for its potential for demonstrating the use of automation technologies for a Space Station subsystem.

The preliminary research rapid prototype thermal expert system (TEXSYS) was developed to examine the problems and evaluate technical approaches to the 1988 demonstration. The rapid prototype was developed using a Symbolics 3670 LISP machine, and the expert-system development environment KEE, and utilizes an object-oriented design with inheritance for representing the physical layout of the thermal system, rules for modeling the behavior of the system, and LISP-based methods for managing implementation-specific bookkeeping details. The prototype provided a preliminary look at thermal-system representations and modeling approaches, qualitative reasoning, and fault diagnosis procedures.

(M. Schwartz, W. Erickson, and C. Wong, Ext. 6525)

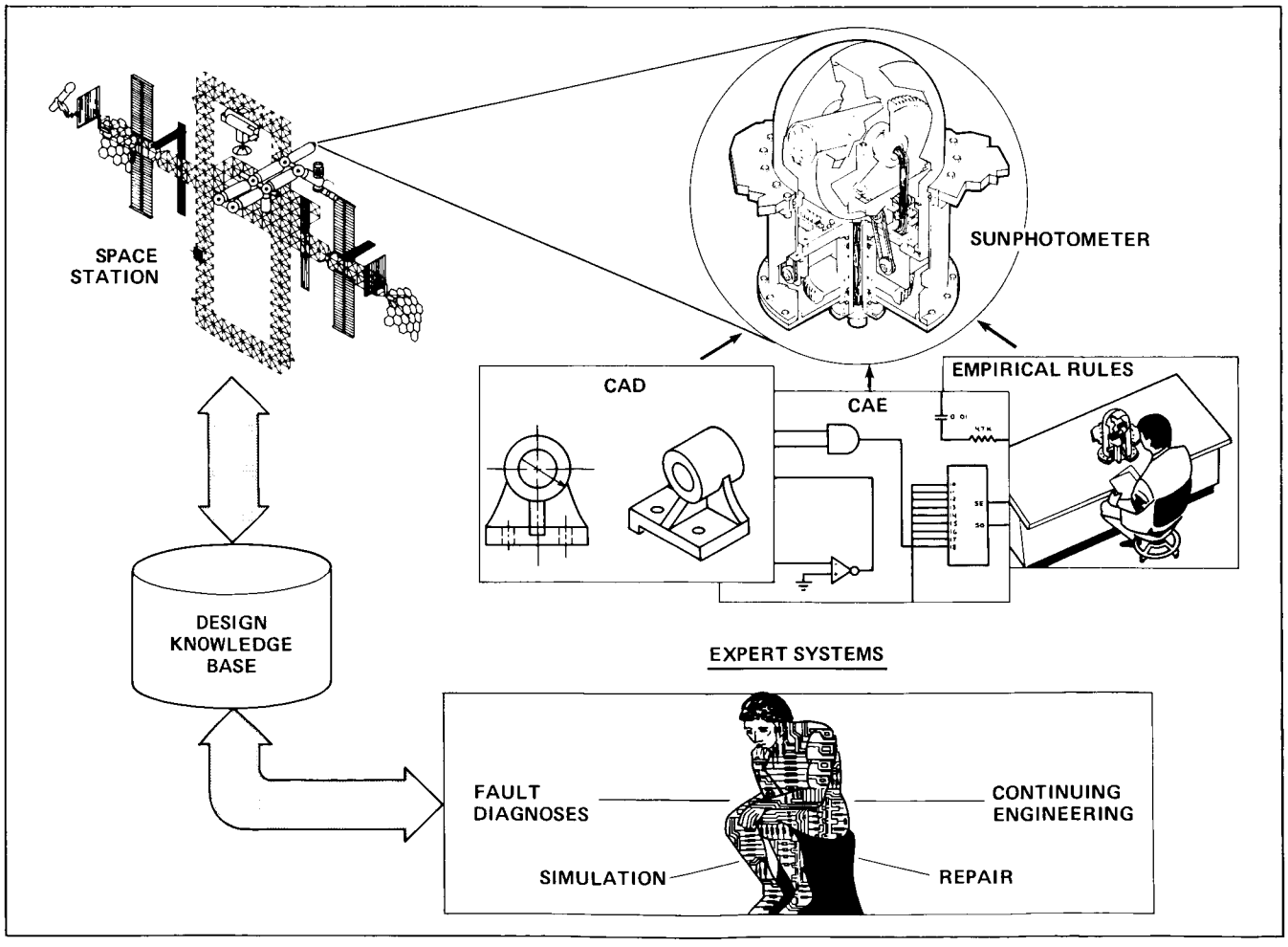
Automated Design Data Capture

Expert systems will find a variety of applications on, or in connection with, the Space Station. The major areas for which expert systems will be developed and for which planning should be pursued are diagnosis, repair, validation, assembly, disassembly, and continuing engineering. Currently, these functions are carried out entirely by humans, usually in a complex process of data reconstruction.

The objective of the automated design data capture project is to capture at least a considerable portion of these functions automatically by expert systems, or semiautomatically by humans, with the help of expert systems. Some of the required knowledge resides in schemata, blueprints, or CAD/CAE-systems, whereas such information as structure, functionality, empirical rules, and design decisions is documented in a less accessible way or not at all.

The required research issues are to define exactly what knowledge is needed to build the expert systems, how to get that knowledge, and how it should be structured in the knowledge base. One question is what the level of granularity is, how small the smallest indivisible component should be to make a manageable, but still functional, system. As a step to find a methodology to capture and store the design knowledge, a model of the airborne sunphotometer was developed at Ames Research Center. A sunphotometer is a system that tracks the sun and measures the intensity of the sun rays to evaluate the constitution of the air in the atmosphere.

The photometer system is composed of both mechanical and electrical subsystems. This combination is crucial since the task to capture the structure and functionality of mechanical and mixed systems is much less explored than that of capturing information about electrical systems. The model is being used to simulate the behavior



Automated design data capture

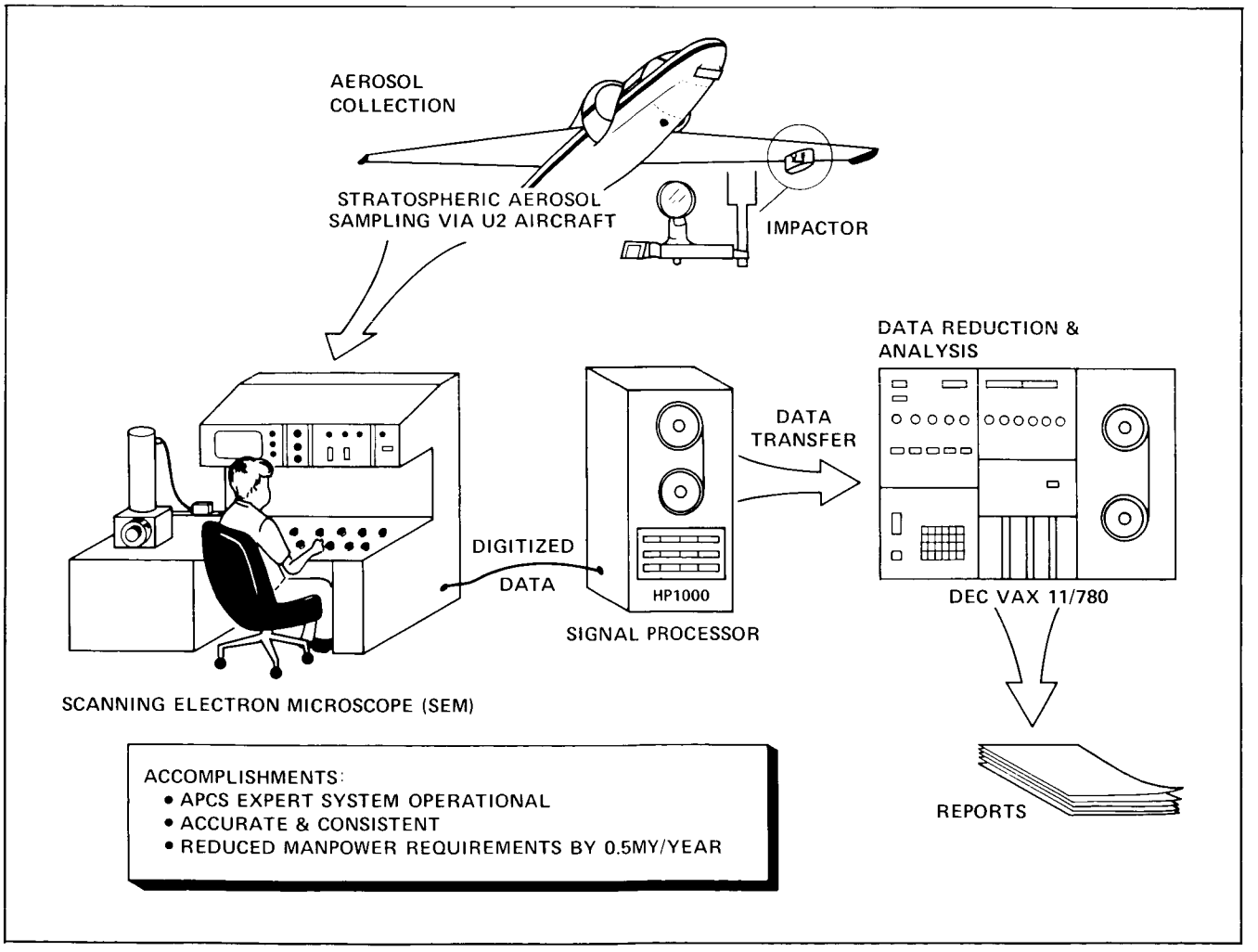
of these different subsystems as well as the whole system. The model will give guidelines to the different designers of the Space Station on documentation of the design information, while giving them maximum freedom to implement their design tasks. By achieving a well structured database and knowledge base, researchers can now use this information to develop expert systems that perform fault diagnosis, etc., in an evolutionary manner.

(C. Sivard, Ext. 6525)

Aerosol Particle Classification System

Impactors are routinely flown aboard Ames Research Center's U2 aircraft in a program of stratospheric aerosol sampling. These impactors have served as both primary sampling devices and calibrators for optical aerosol spectrometer probes. In either case, an accurate distribution analysis of particle size/quantity is of primary importance. This analysis task has historically been performed through tedious and time-consuming manual manipulation of high-magnification photographs of the impactor wires taken with a scanning electron microscope (SEM).

To improve the data-acquisition rate, reduce manpower requirements, improve accuracy, and provide consistency, Ames has developed an aerosol particle classification system (APCS), which is an expert system based on both LISP and C languages, and provides for semiautomatic processing of the impactor science data and report preparation. The hardware component of the APCS provides the SEM operator with an automatic means for digitizing SEM images of the impactors. These images are stored on magnetic tape for both pro-



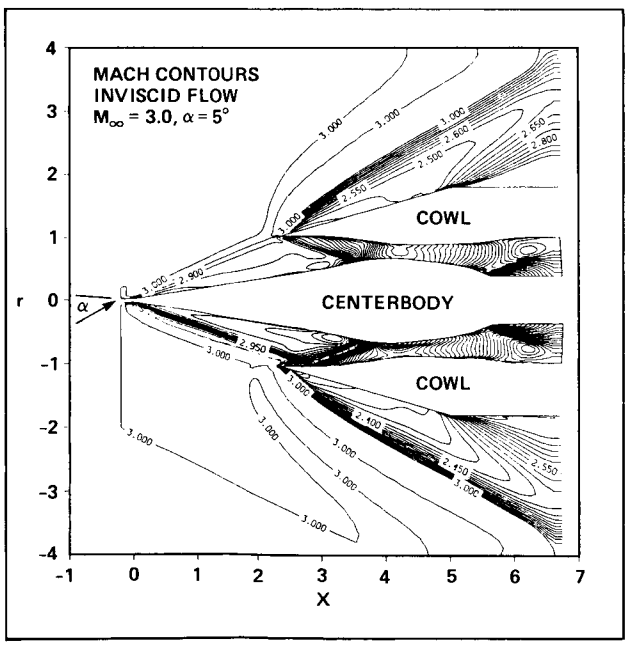
Aerosol particle classification system (APCS)

cessing and archival needs. The expert system software provides for image preprocessing through smoothing, edge detection, image segmentation, and particle classification through the use of feature extractors. The end product of the analysis is an aerosol particle count and size histogram. Comparisons to date have shown that the APCS expert system produces data that are equivalent to those produced by the human observer. Manual analysis of the SEM images will be eliminated, thereby reducing the manpower requirement for data collection, reduction, and analysis by 0.5 personyear/year. Moreover, the system will replace expertise which has been gradually declining because of the tedium of the job.

(L. Webster and L. Netland, Ext. 6526)

Airframe/Inlet Aerodynamics Program

A new computational method was developed that extends the scope of inlet aerodynamic predictions over a variety of flow conditions. The numerical algorithm adopts a combined implicit-explicit approach for solving the unsteady, three dimensional compressible Navier-Stokes equations in conservation form.



Effects of flow incidence ($\alpha = 5°$), supercritical flow without terminal shock Mach contours, inviscid flow, $M_\infty = 3.0$

Initially, the method was used to compute the external and internal inviscid flow field for a mixed compression axisymmetric inlet model. Results were obtained at 0° angle of attack, for supercritical flow conditions without a terminal shock wave, critical conditions with a terminal shock (inlet "started"), and subcritical conditions with the inlet "unstarted." In addition, a flow field was computed for supercritical flow conditions at an angle of attack of 5°. These computations were compared with experimental results obtained from previous wind tunnel tests. The inviscid computations and experimental results compare reasonably well. The major difference is in the location of the terminal shock wave; experimentally it falls slightly farther upstream because of the added compression generated by the boundary layer.

Overall, the computer code is robust and efficient. Efforts are now under way to complete a fully viscous case, including boundary layer bleed, to accurately simulate this complex inlet flow field.

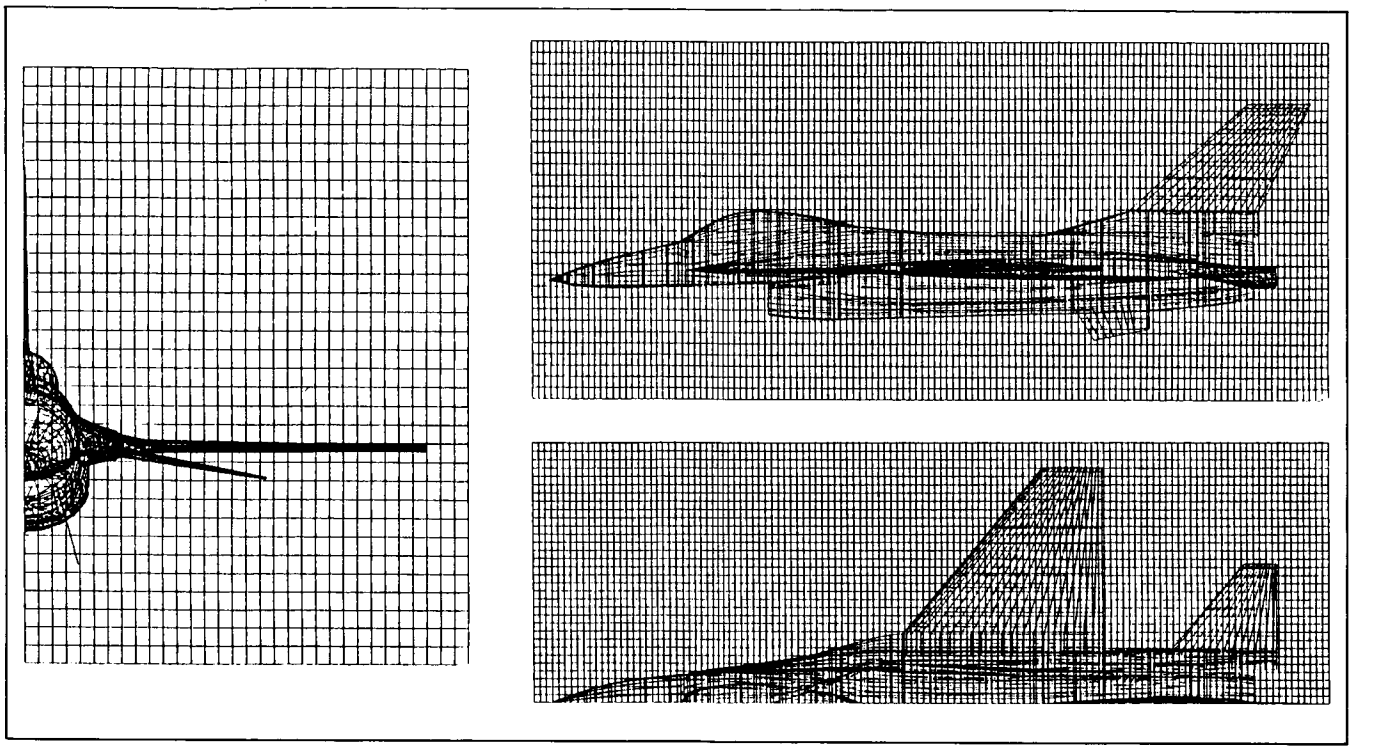
(W. Chyu, Ext. 6208)

TranAir Development

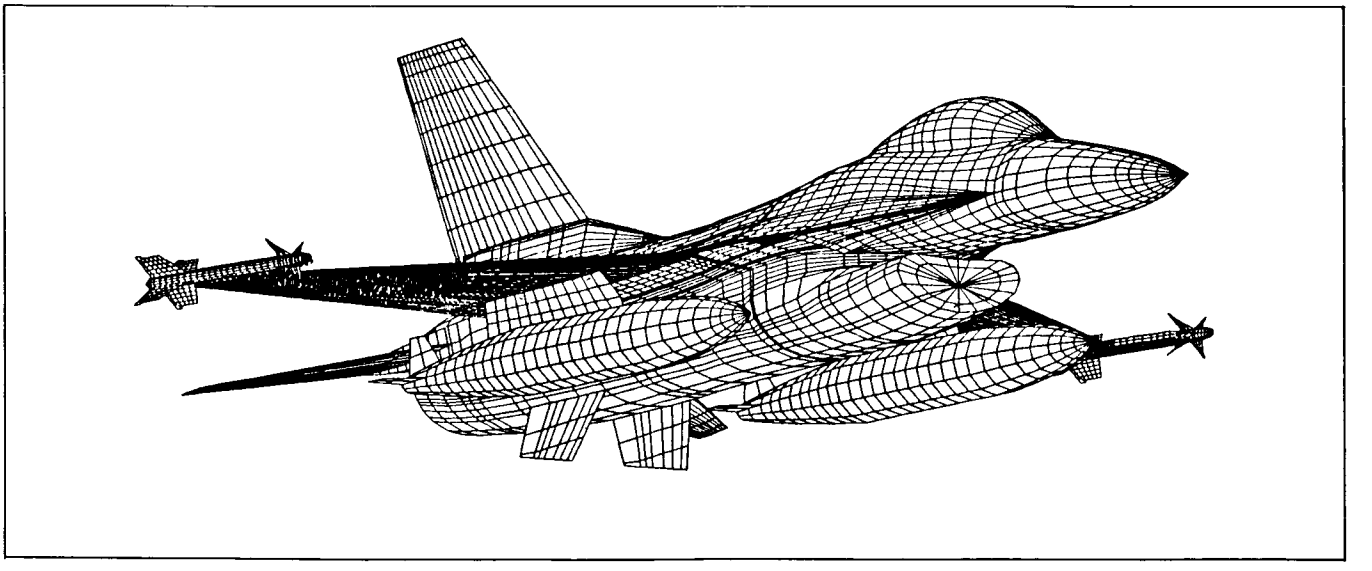
The TranAir computer code solves the conservative form of the full-potential equation to determine the transonic flow about complex aircraft configurations by utilizing finite-element and optimization techniques. The aircraft geometry is defined by surface panels in the same manner as the linear-potential panel methods (i.e., Panair). The surface definition generality associated with the panels enables transonic flow about very complex configurations to be computed without using a surface-conforming flow-field grid. Instead, TranAir solves for the flow by embedding the paneled geometry in a rectangular array of flow-field grid points.

Results have been obtained for the F-16A geometry shown embedded in a 129 by 33 by 33 flow-field grid. A solution for the full configuration is obtained in approximately 3500 CPU sec on a Cray X-MP/48 computer. The plot shows TranAir pressure results plotted with wind tunnel data for M = 0.9, and $\alpha = 4°$. The TranAir inviscid solution predicts the shock on the upper surface of the wing that is evident from the wind tunnel data.

TranAir results are currently being obtained for the F-16A, which has been modified by the addition of wing-tip missiles and launchers and an

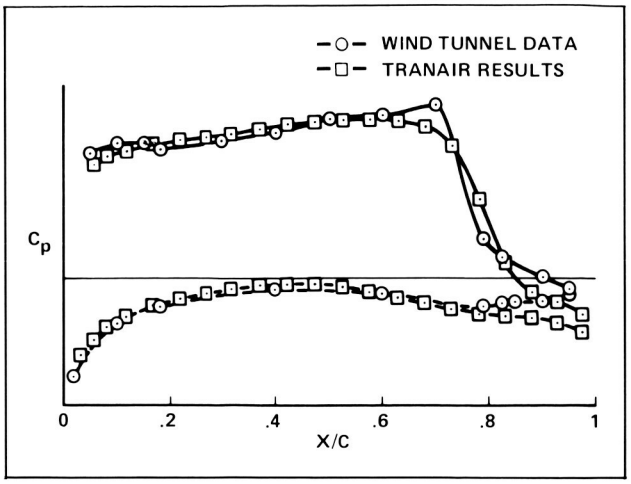


F-16A paneled geometry embedded in a 129 by 33 by 33 rectangular grid



F-16A configured with tip missiles, launchers, and fuel tanks

underwing fuel tank. This configuration is shown. Results are also being obtained for the F-8 oblique wing aircraft, as well as the F-16XL.



F-16A full configuration TranAir results. Tap station 3 (59% semi-span), M = 0.9, $\alpha = 4°$

The code is currently running on the Cray X-MP/48, and will soon be available on the NAS Cray-2. Solutions will then be possible using more than six times the number of grid points currently possible on the X-MP.

(M. Madson and L. Erickson, Ext. 6010/6216)

Joined-Wing Research Aircraft

Ames Research Center has a program to advance the design technology for joined-wing aircraft. This program includes development of structural and aerodynamic design tools, and the design, fabrication, and flight-testing of a joined-wing research aircraft.

The joined-wing concept offers structural weight savings of 15 to 30% compared with conventional aircraft configurations. This weight savings may be exploited as improved range or payload for transport and high-altitude/endurance applications.

Simplified structural and aerodynamic prediction methods have been developed for rapid evaluation of a wide variety of designs and will be used to conduct a realistic comparison study of joined-wing versus conventional configurations for a 150-passenger transport.

The NASA AD-1 oblique wing aircraft will be modified by removing the oblique wing and installing new joined wings. The preliminary design of the airplane is complete and a one-sixth scale wind tunnel model has been built. As the contractor proceeds with the detailed design of the flight research aircraft, NASA personnel will evaluate aerodynamic performance and handling qualities of the design using PanAir analysis and results of tests in the Ames 12-ft wind tunnel.

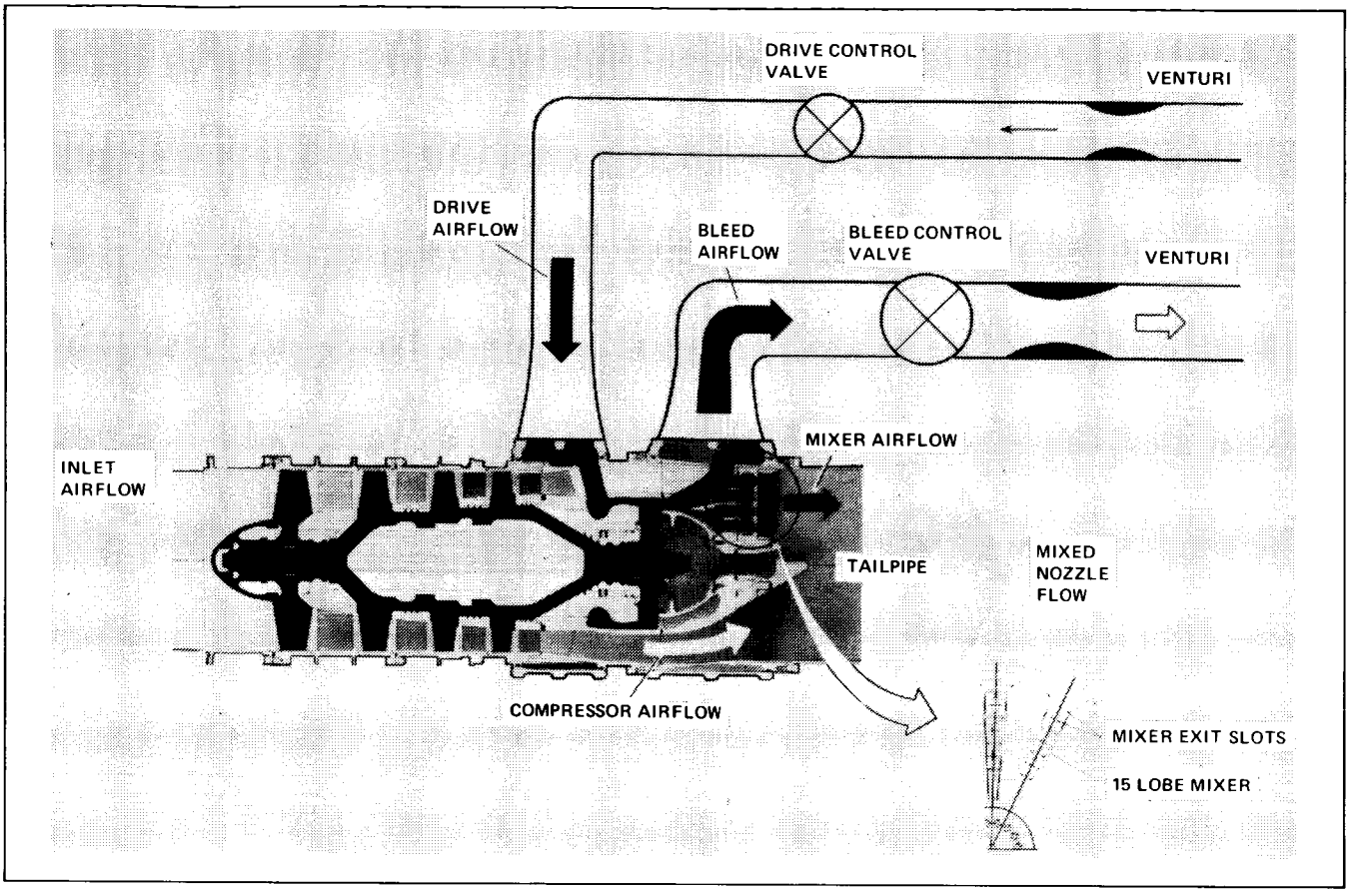
(S. Smith, Ext. 5856)

Compact Multimission Aircraft Propulsion Simulator (CMAPS)

The Compact Multimission Aircraft Propulsion Simulator (CMAPS) was developed to simulate realistic propulsion system airframe interactions during high-speed wind tunnel tests. The techniques for controlling the CMAPS engine and interpreting the data produced by CMAPS are presently being refined at NASA Ames Research Center. Tests conducted recently in the Propulsion Simulator Calibration Laboratory (PSCL) produced useful data toward those objectives.

The high-pressure air, which powers the CMAPS model, presents a challenging seal problem between the drive manifold and the simulator mainframe. A simple modification to the drive manifold O-ring gland (i.e., chamfering the corners of the gland) prevented the seal from being severed during assembly. In this way, the integrity

CMAPS calibration in 9- by 7-in. test section



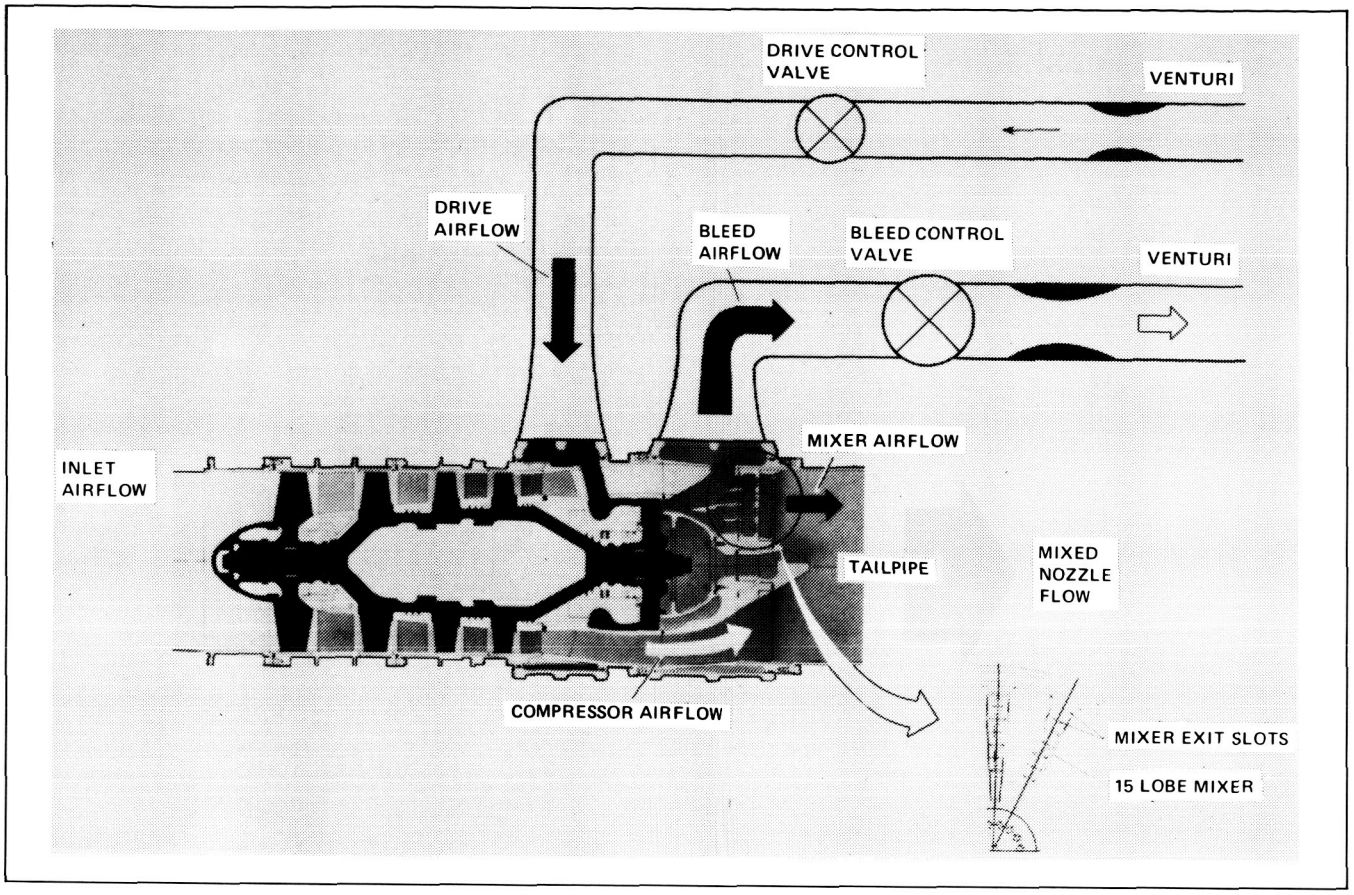
CMAPS airflow schematic

of the drive air system/model interface is effectively maintained.

The CMAPS engine is controlled by a digital computer system designed expressly for this application. In addition to manual mode, the controller can be set to seek a desired rotor speed setpoint or, in fully automatic mode, a specified set of engine pressure ratio and compressor airflow coordinates. By modifying the controller software to average the data used by the controller in the fully automatic mode, the time required to make the transition from setpoint to setpoint was minimized, thus saving valuable operating time.

Baseline operating data were obtained in the PSCL with the CMAPS engine in both a reheat mixer configuration and jet effects mixer configuration. This information will be added to the growing data base which will be useful for interpreting future wind tunnel test results. As these propulsion simulation test techniques improve, they will prove to be a viable wind tunnel test tool in the future development of advanced aircraft configurations.

(M. Won and D. Wilson, Ext. 6463/6134)



CMAPS airflow schematic

of the drive air system/model interface is effectively maintained.

The CMAPS engine is controlled by a digital computer system designed expressly for this application. In addition to manual mode, the controller can be set to seek a desired rotor speed setpoint or, in fully automatic mode, a specified set of engine pressure ratio and compressor airflow coordinates. By modifying the controller software to average the data used by the controller in the fully automatic mode, the time required to make the transition from setpoint to setpoint was minimized, thus saving valuable operating time.

Baseline operating data were obtained in the PSCL with the CMAPS engine in both a reheat mixer configuration and jet effects mixer configuration. This information will be added to the growing data base which will be useful for interpreting future wind tunnel test results. As these propulsion simulation test techniques improve, they will prove to be a viable wind tunnel test tool in the future development of advanced aircraft configurations.

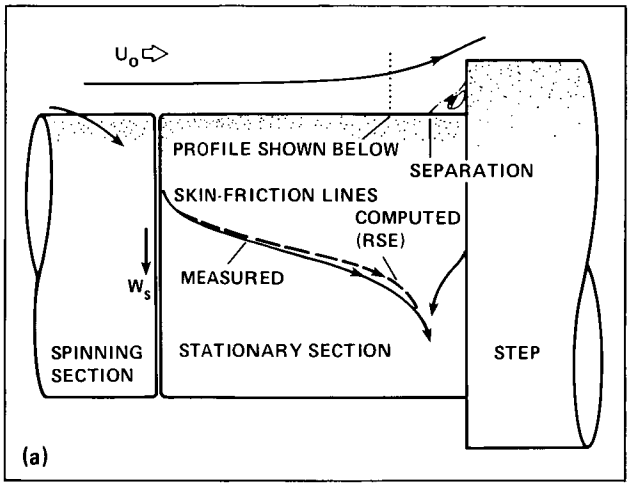
(M. Won and D. Wilson, Ext. 6463/6134)

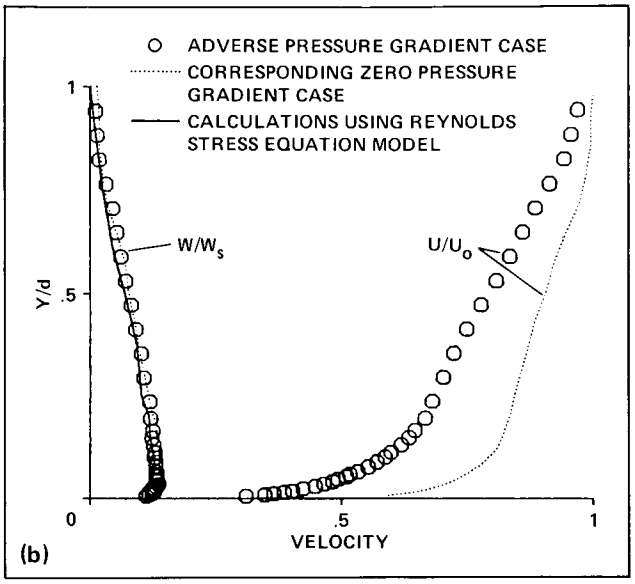
Measurements in a Separating Three-Dimensional Turbulent Flow

Details of a three-dimensional (3-D) flow separation are difficult to study because of complex geometries and the need for sophisticated instrumentation. Therefore, a simplified experimental geometry was devised to retain the features of 3-D separating flow while reducing the geometrical complexity. The configuration shown produces a swirling flow (induced by a rotating cylinder) which is deposited onto a stationary section of cylinder; here the flow loses cross-flow momentum (caused by skin-friction) while encountering an adverse pressure gradient (produced by a forward-facing step). This geometry offers axisymmetry, which simplifies the governing equations of motion and the computational expense.

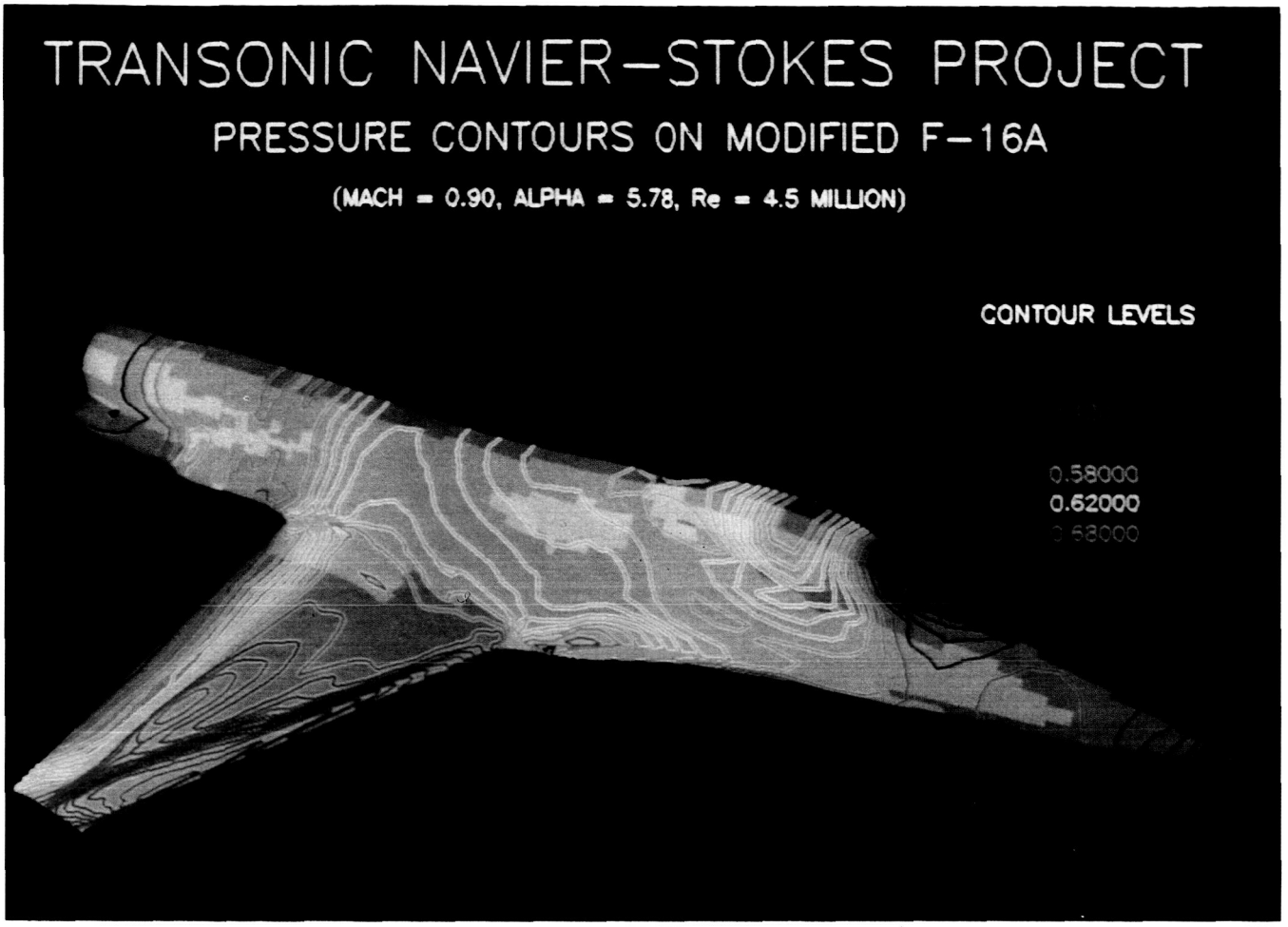
Measured surface-skin-friction lines, along with computed skin-friction lines (using a Reynolds stress equation turbulence model), can be seen to compare quite well. The effects of the adverse pressure gradient on the streamwise component of velocity can be seen in the adjacent figure, resulting in a severely retarded flow near the wall. Surprisingly, the cross-flow component of velocity is virtually unaffected, relative to the zero pressure gradient case (no forward step). The cross-flow velocity predicted by the Reynolds stress equation model agrees very well with that measured.

(D. Driver and S. Hebbar, Ext. 6156)





Three-dimensional separated flow measurements; a) measured flow pattern; b) velocity profile upstream of separation

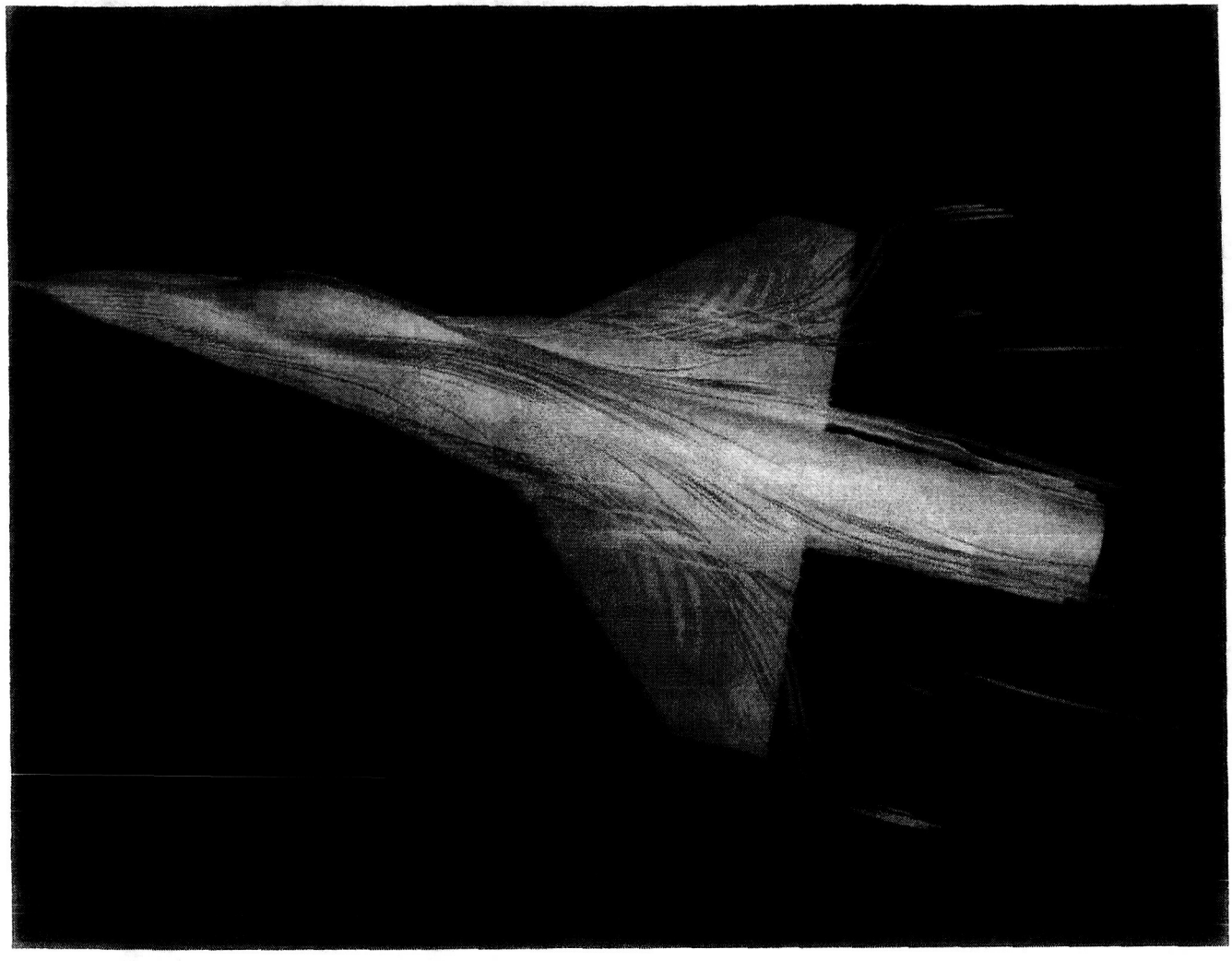


Surface pressure contours; $M_\infty = 0.9$, $\alpha = 5.78°$, and Re = 4.5 million

Transonic Navier-Stokes Project

The Transonic Navier-Stokes (TNS) Project has been initiated to develop computational procedures and associated computer codes for the solution of flow fields about complete three-dimensional aircraft configurations. The thin-layer, Reynolds-averaged, Navier-Stokes equations will be solved using a block- or zonal-grid structure. This block-grid structure is used for two purposes. First (and most importantly), it serves to improve the distribution of grid points about complicated geometries. That is, grid blocks far removed from large flow gradients can be relatively coarse while grid blocks near large flow gradients can be fine. Second, since the solution from only one grid block will reside in main memory at a time, the block-grid approach provides a convenient mechanism for organizing the data base. Research opportunities associated with the TNS Project are in the following areas: surface geometry representation, grid-generation algorithm development, flow-solver algorithm development and/or improvement, and graphical display of geometric and flow-field results. In addition, fundamental studies involving the numerical solution of flow-field physics about realistic configurations are anticipated.

The attainment of flow about the complete F-16 is the final goal of this project. The first phase in the development of this code will be to simulate the flow over the F-16 with the inlet faired over and without the tail-assembly. The figure shows the pressure contours on the aircraft for flow conditions of $M_\infty = 0.9$ and $\alpha = 5.78°$, and a Reynolds number of 4.5 million. The stag-



Three-dimension particle traces; $M_\infty = 0.6$ and $\alpha = 10.0^\circ$

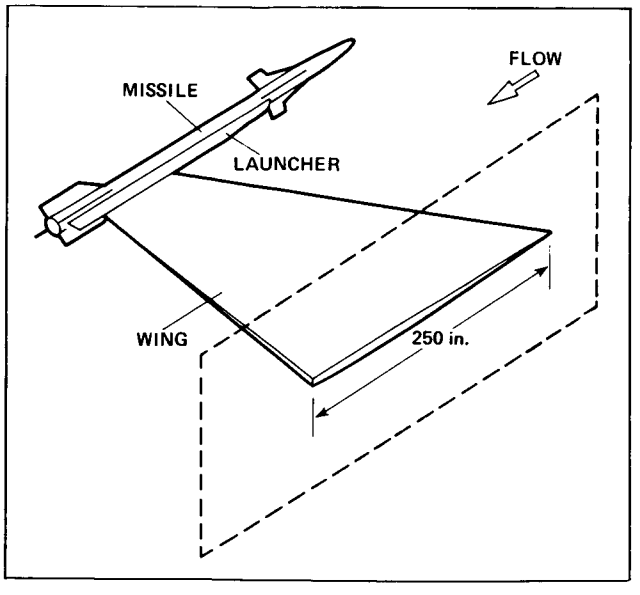
nation regions (low pressure) can be seen to occur at the leading edge of the fuselage and forward of the canopy. A double shock pattern can be seen on the wing, with the corresponding jump in pressure downstream of each shock. The other figure shows a different case, $M_\infty = 0.6$ and $\alpha = 10.0^\circ$, and laminar flow. In this illustration we trace the path of particles which are released along the fuselage and at the leading edge of the wing, near the root. The particles change color to indicate their height above the wing, blue indicating low elevation and yellow indicating high elevation. We can see that the particles along the strake region form a vortex which continues downstream and goes under the vortex (formed from the leading edge of the wing) and outboard. The solid red traces on the wing are particles constrained to the surface and simulate the oil flow on the wing. We can discern a separation line, a reattachment line, and a standing vortex on the wing. This solution was obtained with 16 grids (a total of 270 thousand grid points) on the Cray/XMP-48 and required about 10 hr of cpu time.

(J. Flores, Ext. 5369)

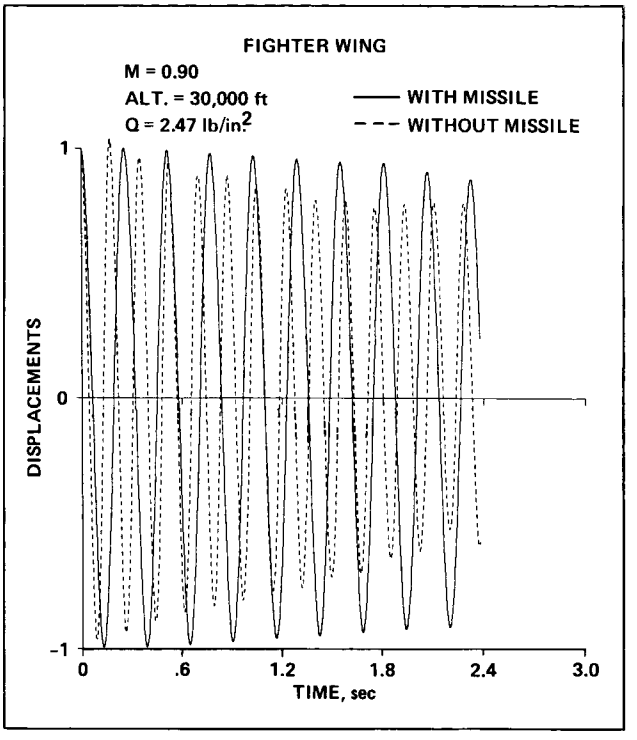
Computer Simulation of Transonic Aeroelasticity of Wings with Tip Stores

Tip stores change the aerodynamic and aeroelastic characteristics of wings because of their aerodynamic, inertial, and elastic coupling with the wings. Because of the lack of efficient computational tools at transonic speeds, store aerodynamics has been neglected in flutter analysis. Several experimental studies for such fighter aircraft as F-16 have shown that the tip aerodynamics significantly influences flutter results at transonic speeds. The influence of the tip store on the wing flutter characteristics can be noticeably pronounced in the transonic regime because of the presence of shocks. Here for the first time, the tip store has been theoretically modeled for both aerodynamic and aeroelastic analysis of wings in the transonic regime. Theoretical simulation is done by simultaneously solving unsteady transonic small perturbation aerodynamic equations of motion and structural modal equations of motion by a time-accurate numerical method. This new capability has been incorporated into the Air Force/Ames Research Center code XTRAN3S. This work was conducted with joint collaboration with Eglin and Wright Patterson Air Force Bases.

Detailed steady and unsteady aerodynamic computations were made for the F-5 wing with a tip missile. The computed results compared well with available wind tunnel data. It was noticed that the tip missile has significantly more influence on the wing aerodynamics at transonic Mach numbers than at subsonic Mach numbers. The influence of the tip missile on the unsteady pressures was greater than that on the steady pressures.



Typical fighter wing configuration with a tip missile



First-normal modal responses of the fighter wing with, and without, tip missile

Aeroelastic studies were conducted for a typical rectangular wing and for a typical fighter wing with a tip store. Detailed computations for a rectangular wing showed that the tip store aerodynamics can make the wing aeroelastically less stable. Limited computations for a typical fighter wing based on the F-5 wing planform also illustrated the same phenomenon.

Since the simulation in this analysis is close to wind tunnel simulation, the present development can be an efficient complement to wind tunnel/flight tests and can reduce the design costs considerably. Results of this study will be of valuable use in the area of active flutter suppression at transonic Mach numbers.

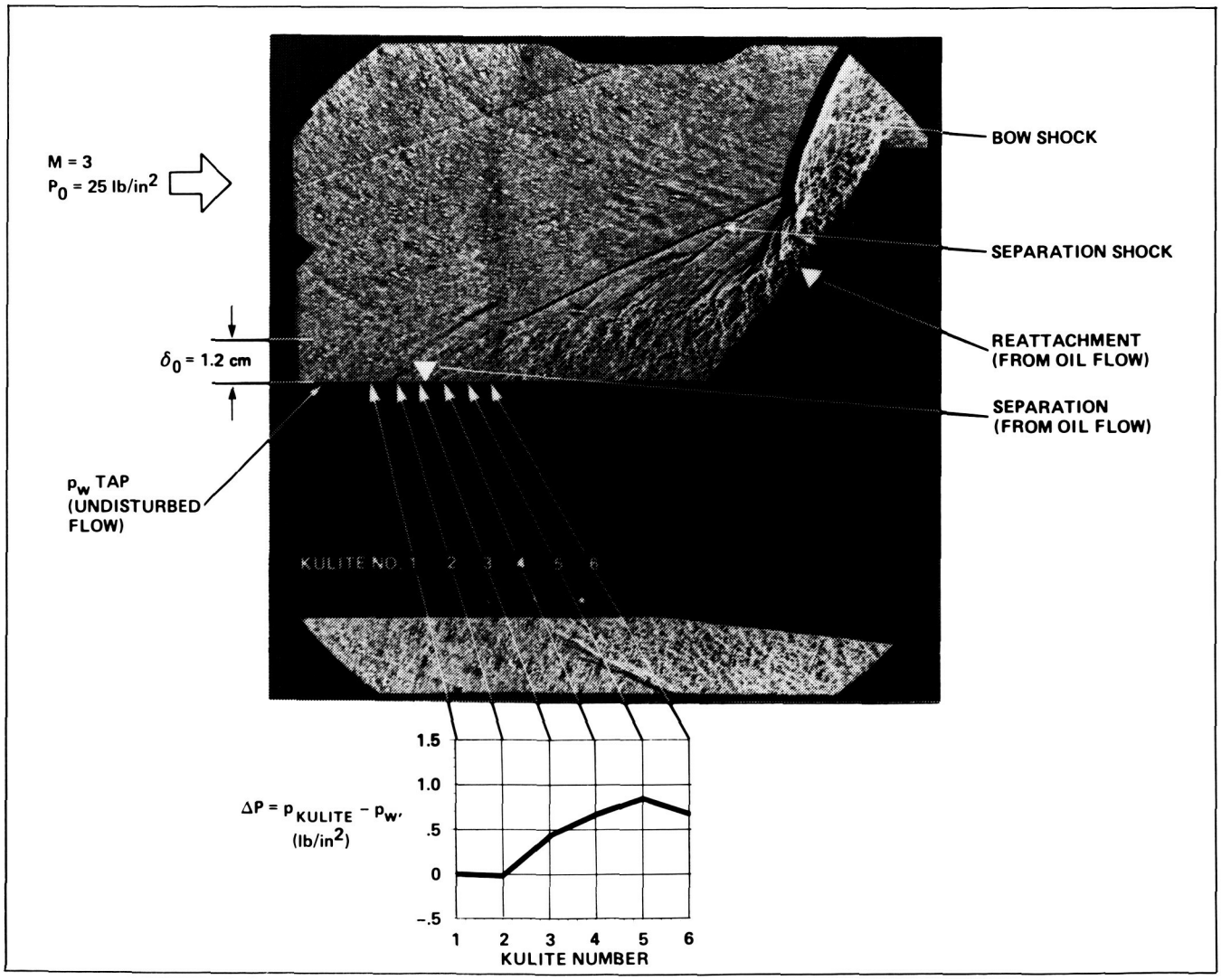
G. Guruswamy, P. Goorjian, and E. Tu,
Ext. 6329/5547/4051)

Measurement of a Complex, Unsteady, Turbulent Flow Field

A unique experimental study of a series of three-dimensional (3-D) flow fields, with massive separation and high unsteadiness, was undertaken in the Ames Research Center's High Reynolds Channel I. The object of the test program was to study the complex 3-D shock-wave/boundary-layer interactions that occur in many practical aerodynamic situations and to assess computational methods used to numerically predict these flows. The experimental setup consisted of a series of conical flares mounted at an angle of attack on a long cylinder, whose axis was aligned with the flow.

This flow consisted of a large, unsteady, separated region (in extent, many times the boundary layer height) and an associated unsteady separation shock whose longitudinal excursions were observed to be more than twice the boundary layer height. High-speed shadowgraph movies of the fluctuating shock wave were taken and individual sequential frames collated, with surface pressures obtained at the same instant. The results of this comparison showed that the shock position and direction could be predicted to a high degree of certainty as a function of the high-frequency surface pressure measurements. Using a laser Doppler velocimeter (LDV), both mean and fluctuating turbulent quantities were obtained throughout this unsteady flow field, and these quantities could be tied to a surface measurement directly related to the shock position in this flow field. The data analysis is under way.

Several conditional sampling methods are being investigated which would, in effect, freeze the



Test setup

flow into a series of "snapshots," each of which contains a sufficient amount of data for a statistical meaningful analysis. Preliminary conditionally sampled results of the "shock upstream" and "shock downstream" data indicate similar separated flow-field zones translated about one to two boundary-layer lengths. Computations of this complex flow have been made, using mass-averaged, time-dependent Navier-Stokes solutions with a two-equation k-ϵ turbulence model. The predictions capture the essence of this 3-D flow. However, certain critical details (such as the separation and reattachment points, the shape of the separated region, and the location of the horseshoe vortex) are miscalculated.

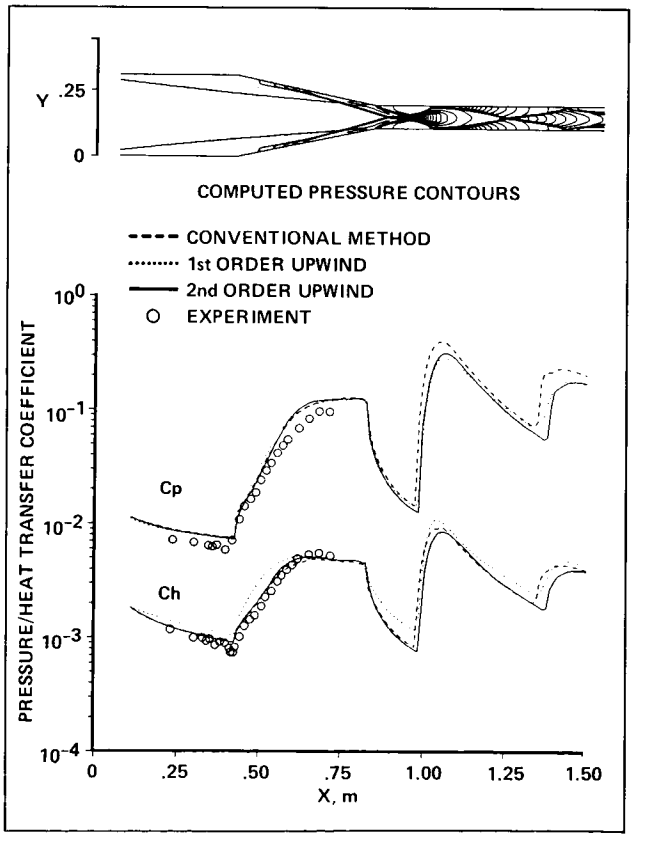
Further analysis of these data should indicate possible flow-model modifications to improve the accuracy of the predictions of the mean flow data. There are at present no computations with which to account for the random unsteadiness present in this flow.

(M. Kussoy, J. L. Brown, and J. D. Brown, Ext. 6200)

An Upwind Algorithm for the Parabolized Navier-Stokes Equations

The design of future hypersonic flight vehicles will depend heavily on computational fluid dynamics for the prediction of aerodynamic and thermodynamic loads as well as engine performance. One of the features that characterizes the hypersonic flow regime is the presence of very strong shock waves generated by the leading edge of the vehicle and by any protuberances from the main body, such as wings, canopies, or engine inlets. In the numerical calculation of these flows, the outer shock wave can easily be "fit" (i.e., treated as a boundary condition); however, shocks generated within the main shock layer are most conveniently "captured" by the numerical algorithm. Thus, a need exists for an efficient computational tool which can easily and accurately resolve flow fields containing discontinuities. Upwind algorithms have received a great deal of attention in recent years for application to the unsteady Euler and Navier-Stokes equations owing to their exceptional shock-capturing capabilities. The development in 1986-87 of an upwind Parabolized Navier-Stokes (PNS) code is an attempt to merge the desirable shock-capturing characteristics of upwind schemes with the efficiency of a space-marching solution procedure.

During 1986, the two-dimensional version of the new PNS code was completed. Results of this code applied to the hypersonic flow over a 15° ramp/inlet combination are shown in the accompanying figure. The pressure contour map illustrates the inviscid phenomena of this flow field, including the weak leading-edge shock; a very strong ramp-induced shock; a rapid expansion at the top of the ramp; and the shock/shock, shock/expansion, and expansion/expansion interactions of the internal region of the configuration. Comparison with experiment is shown for wall pressure and heat-transfer coefficients and it is observed that both the conventional algorithm and the second-order upwind algorithm compare well where data are available. However, the conventional algorithm required the addition of user-specified "smoothing" terms to obtain a solution, whereas they were unnecessary with the upwind code. The flow conditions of this case were a freestream Mach number of 14.1 with a Reynolds number of 2.37×10^5/m. The cpu times required to perform these calculations were approximately



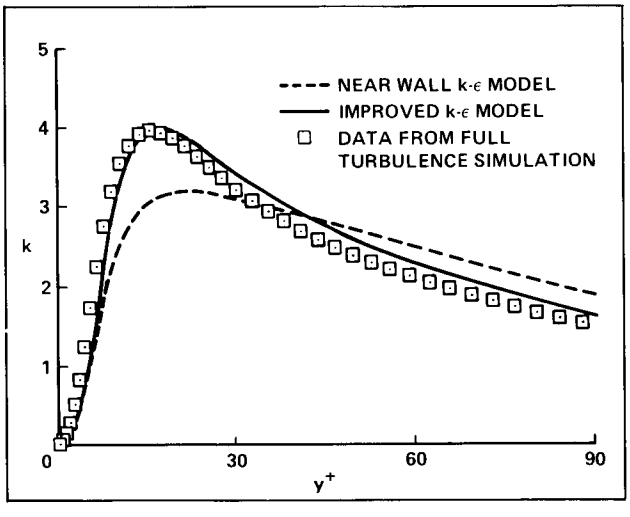
Hypersonic ramp/inlet flow

10 sec for the conventional method and 26 sec for the upwind method on the Cray-XMP computer at Ames Research Center. The calculations were performed using 45 mesh points in the y direction. The three-dimensional version of the code is being validated.

(S. Lawrence and D. Chaussee, Ext. 4050)

Near Wall k-ϵ Turbulence Model

Of the models used to simulate turbulent flows, a popular model is the two-equation model known as the k-ϵ model. This is the most commonly used model developed for high-Reynolds-number flows and is used in wall-bounded flows in conjunction with wall functions to patch the core regions of the flow to the walls.



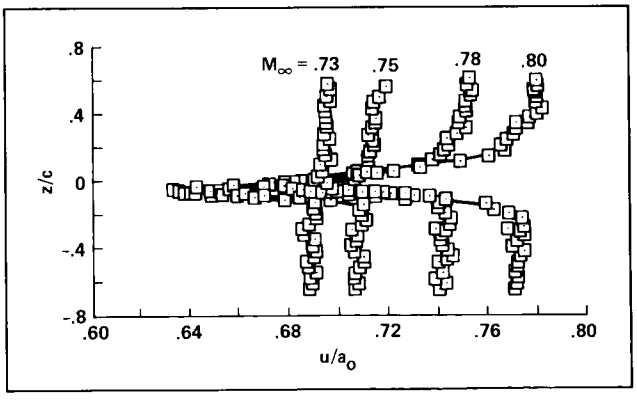
Mean turbulence kinetic energy profile

A k-ϵ turbulence model that will be valid to the wall will not require wall-functions, and can be used in separated regions and highly three-dimensional boundary layers where wall-functions are not valid. The turbulence data from a full turbulence simulation of the channel were used to compute the k and ϵ budget. These budgets (needed for model development) are extremely hard to measure, especially in the near wall region. An analysis of these budgets suggested a near-wall model simpler than existing near-wall models. When this model is used in a turbulent channel calculation it can be shown (solid line) that the peak in the turbulence kinetic energy can be captured by the improved model.

(N. Mansour, J. Kim, and P. Moin, Ext. 6420/5867/5127)

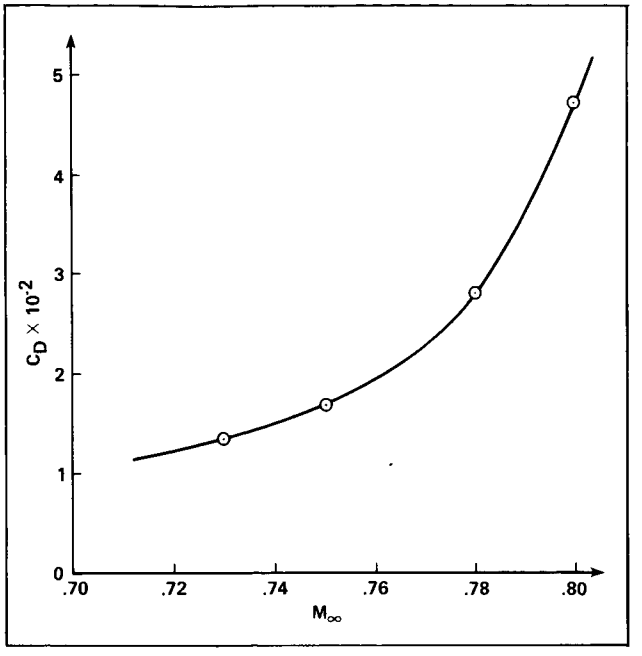
Drag Measurements on a Supercritical Airfoil in Transonic Flow

The development of computational fluid dynamics relies heavily upon the availability of an experimental data base for code verification. This is particularly true for viscous flow codes that utilize turbulence modeling. A recent experiment in the Ames Research Center's High Reynolds Channel II provided data on such a viscous flow. The investigation is significant because it was conducted on a supercritical airfoil at conditions where the viscous effects are a strong function of Mach number. In addition, the measurements were made in a flow that was essentially unaffected by tunnel walls because of wall contouring and suction. Also, a new, unobtrusive laser Doppler velocimeter system was used to obtain the data without disturbing the flow.



Wake profiles for MBB/VA-2; x/c = 2.5, Re = 6x10^6, $\alpha = 1^\circ$

The wake and drag data shown on the accompanying figures are examples of the type of measurements that will be used to evaluate codes. The wake data will test the simulation's ability to describe the local features of the flow. The drag data can be used to assess the global description.



Drag data for MBB/VA-2 airfoil; Re = $6x10^6$, $\alpha = 1°$

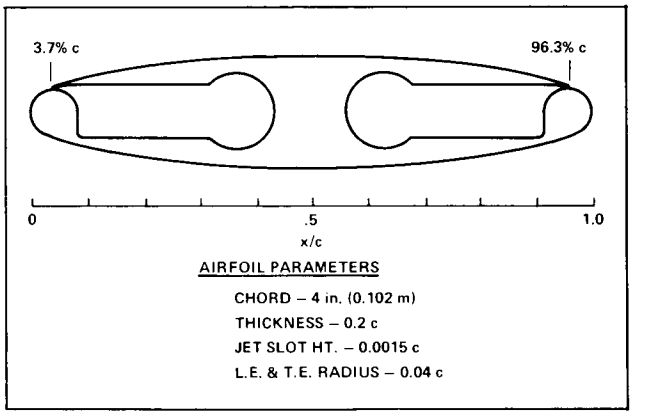
Data sets such as these, taken on complex, realistic shapes are essential in establishing the validity and credibility of numerical simulations of viscous flows.

(G. Mateer, H. Seegmiller, and L. Hand, Ext. 6156/6211/6200)

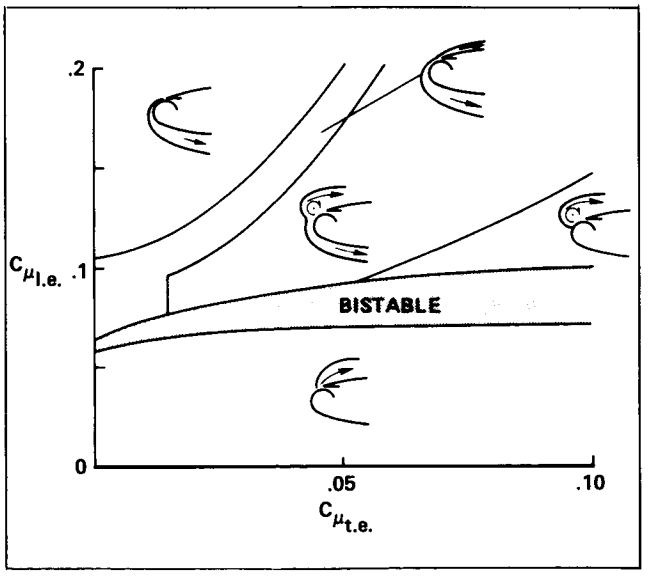
Study of a Circulation Control Airfoil with Landing/Trailing-Edge Blowing

The term "circulation control" is used here to denote a method of lift generation that utilizes tangential jet blowing over the upper surface of a rounded trailing edge airfoil to determine the location of the boundary-layer separation points. Circulation control of this type applied to rotorcraft can eliminate the forward-flight speed limitations caused by conventional-rotor retreating-blade aerodynamic problems, lift loss which is due to reverse flow and dynamic stall. This control is accomplished using rotor blade sections that are symmetric about midchord, with upper surface leading- and trailing-edge jet-blowing slots, permitting simultaneous blowing on each edge of the retreating blade and thus enabling the development of high-lift coefficient values with the flow relative velocity coming from either direction. At present little information exists on the flow structure generated by circulation-control airfoils under leading-edge blowing.

In view of this lack of information, an experimental study was undertaken of the flow field generated by a two-dimensional circulation-control airfoil under steady leading- and trailing-edge blowing. The experiments were performed in the closed-circuit water tunnel of the Army Aeromechanics Laboratory at Ames Research Center. The airfoil tested (see first figure) had an



Study of a circulation airfoil



Map of leading-edge jet flow-field structure: $\alpha = 0°$

uncambered elliptical section with circular arc leading and trailing edges, and upper surface leading- and trailing-edge jet slots. The study ascertained the effect of varying jet blowing momentum on the flow field for 0° angle of attack and for Reynolds numbers, based on chord, up to 400,000. Measurements were made of the mean and fluctuating forces. Flow visualization was also performed.

The behavior of the leading-edge jet was found to be more complicated than hypothesized by previous investigators. The observed leading-edge jet behavior is indicated schematically in the second figure. This "map" of the leading-edge flow structure was made through correlation of the flow-visualization observations with the leading- and trailing-edge jet-momentum settings. A noteworthy finding is that, for certain conditions, leading-edge blowing results in a pronounced unsteadiness in the lift. The bistable region in the second figure indicates this unsteady flow condition.

(B. McLachlan, Ext. 4142)

Experimental and Computational Studies of Plane Mixing Layers

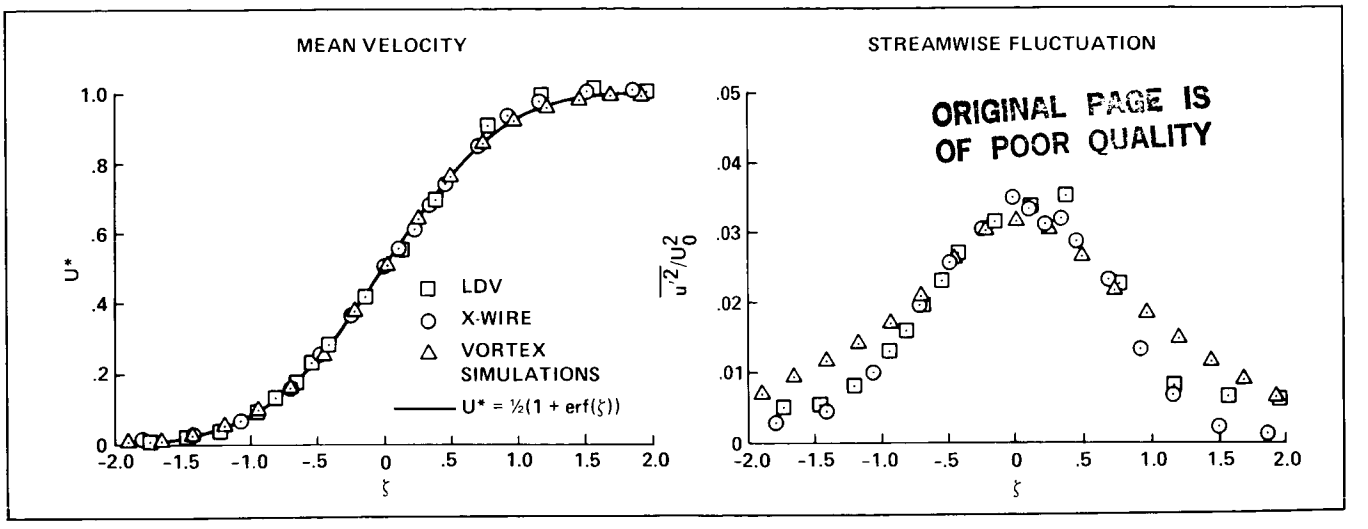
Some experimental and computational studies of forced and unforced two-dimensional (2-D) turbulent mixing layers have been completed in an effort to increase our basic understanding of this important shear flow. The experimental results included flow-visualization data using the smoke-laser technique, and mean flow and turbulence measurements using X-wires and a two-component laser-doppler velocimeter (LDV). Two computational studies of the measured mixing layers were also conducted in a coordinated effort; one using the discrete vortex method and the other based on Reynolds-averaged Navier-Stokes equations.

The first figure shows a comparison between X-wire and LDV measurements, and the vortex method computations in the self-preserving region of a two-stream mixing layer. The agreement between the three techniques of the mean flow behavior and peak levels of the Reynolds stress ($\overline{u'^2}$) is extremely good, to well within 10%. The distribution of the streamwise fluctuation also agrees well, although the computed levels fall off more slowly toward the mixing-layer outer edges. However, the computed values of the normal fluctuation ($\overline{v'^2}$) were found to be higher by a factor of about four. This was attributed to the presence of longitudinal vortices in the measured flows which would tend to relax this normal stress; this phenomenon could obviously not be simulated in the 2-D computations. Work is in progress on developing a three dimensional (3-D) vortex method in which this particular feature of the shear flow will be included.

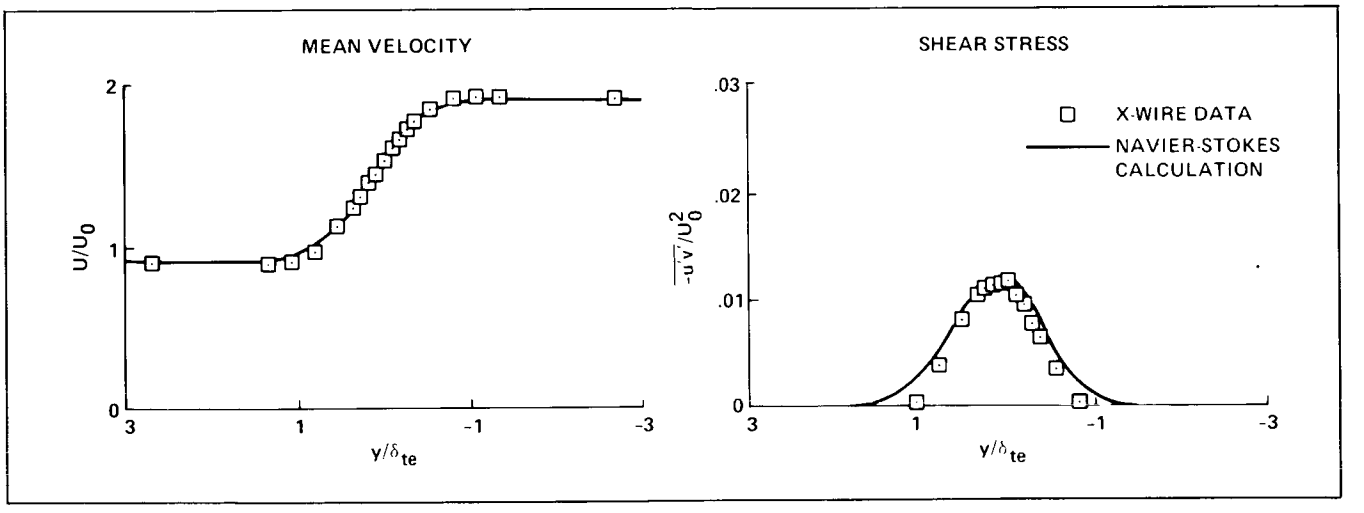
The Reynolds-averaged Navier-Stokes computation was started from the splitter plate edge using the measured boundary-layer profiles as input. The computed mean velocity profile just downstream of the splitter plate reproduced the plate wake extremely well. Farther downstream, in the self-similar region, the computed results for both the mean velocity and shear stress compared well with the measurements as shown in the second figure. This computational scheme was thus able to capture the near-field behavior, which included the plate wake, and then relaxed to a self-similar solution in the far field, in agreement with the experimentally observed trends.

Data for mixing layers forced at the origin were also compared directly. A hinged flap was mounted on the splitter plate trailing edge and oscillated in the vertical plane to produce the forcing in the experiments. In the vortex method, the forcing was simulated by imposing a sine function on the vertical component of the mean velocity. The third figure shows some flow visualization results compared to the distribution of discrete vortices as given by the vortex simulations when the forcing was at twice the "natural" frequency. This is the case when vortex pairing and hence mixing layer growth are suppressed right from the start; this particular trend is reproduced very well in the simulations. The quantitative data from the vortex method were also compared to LDV measurements and excellent agreement was found.

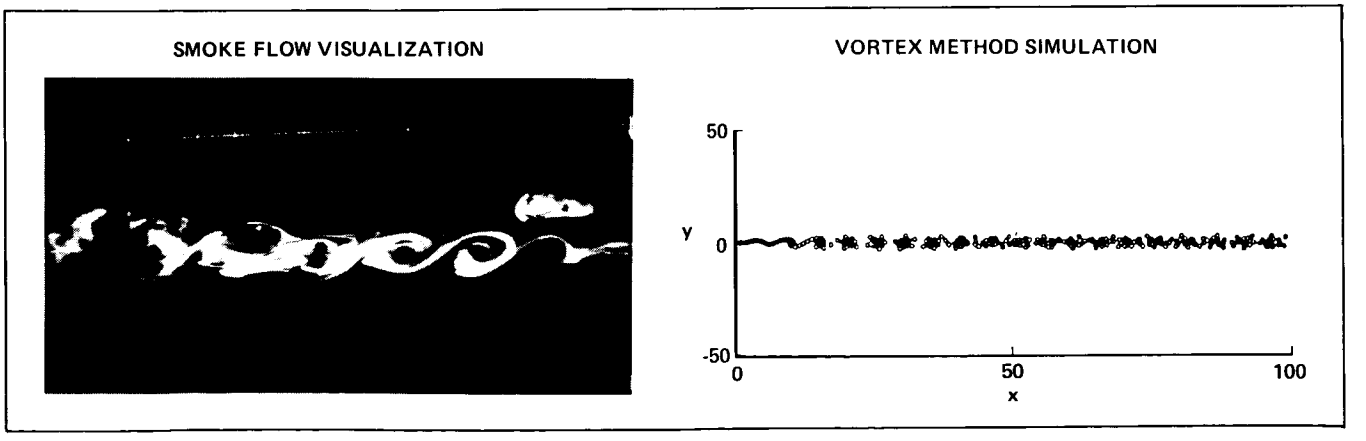
(R. Mehta, O. Inoue, L. King, and J. Bell, Ext. 4141/6667/6116)



Comparison of X-wire and LDV measurements and vortex method computations for the unforced mixing layer in the self-similar region, velocity ratio = 0.5



Computation using Reynolds averaged N-S equations compared with X-wire measurements in the self-similar region



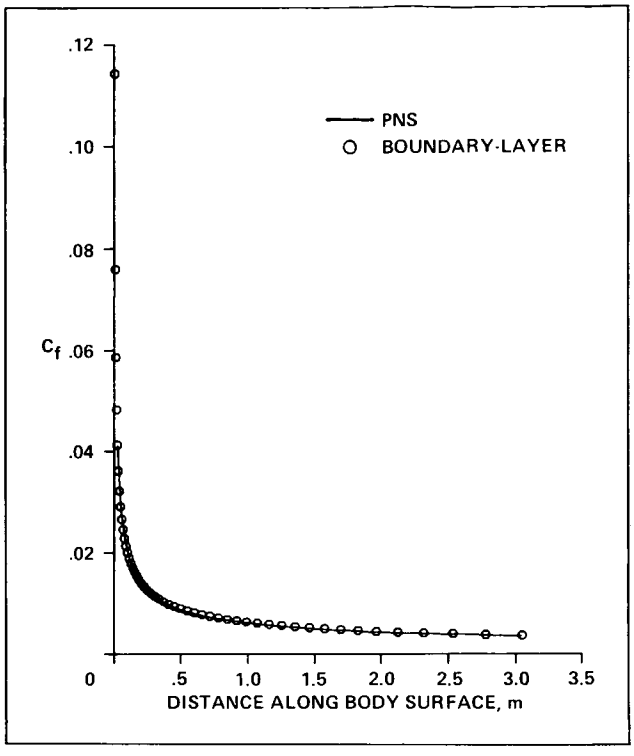
Qualitative comparison for forced mixing layer. Forcing at twice the natural frequency, velocity ratio = 0.5

A New Parabolized Navier-Stokes Code for Chemically Reacting Flow Fields

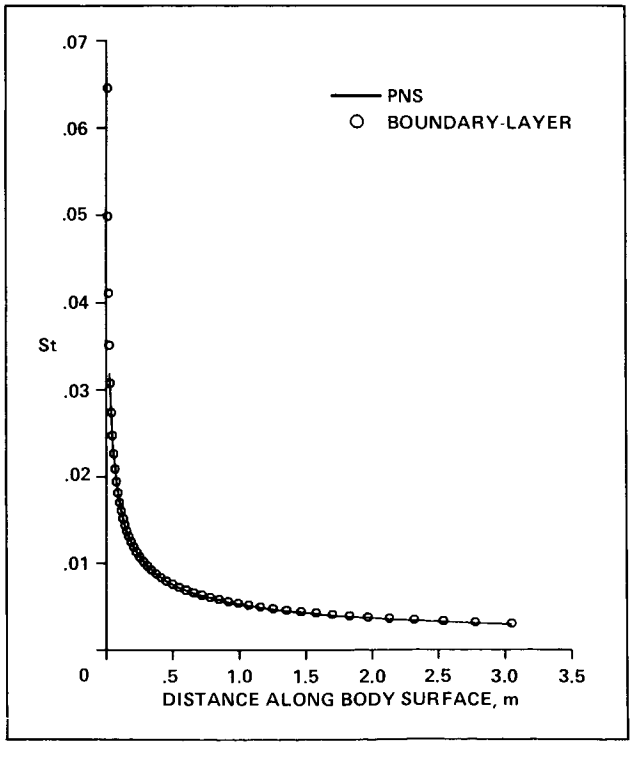
The new generation of proposed hypersonic vehicles such as the aeroassisted orbital transfer vehicle (AOTV), aeromaneuvering orbital transfer vehicle (AMOTV), etc., are likely to be characterized by shock layers that are predominantly in thermochemical nonequilibrium. Because of the current lack of ground-based experimental facilities, such complex flows have to be simulated numerically.

In the past, the parabolized Navier-Stokes (PNS) equations have been successfully applied to hypersonic viscous flows of ideal gas and equilibrium air over three-dimensional (3-D) configurations. During FY 86, a new PNS code was developed to compute the hypersonic, laminar flow of a chemically reacting mixture of thermally perfect gases over two-dimensional (2-D) and axisymmetric bodies. This code solves the coupled set of gasdynamic and species conservation equations using a noniterative, implicit, space-marching technique. The PNS equations are hyperbolic-elliptic in the "streamwise" or marching direction if the pressure gradient in that direction is completely retained in the subsonic portion of the flow and is consequently ill-posed for a space-marching method of solution. The problem is "parabolized" or made well-posed by retaining only a fraction of the pressure gradient in the streamwise direction. The magnitude of the fraction retained was derived using an eigenvalue analysis and was found to be dependent on the local frozen Mach number.

In order to validate the code, a number of test problems were solved. In all the test cases, the flow medium was assumed to be chemically reacting air consisting of molecular nitrogen, atomic nitrogen, molecular oxygen, atomic oxygen, and nitric oxide. Only two of the test cases are presented here. In the first test problem, the hypersonic laminar flow (M = 25, Re = 150,000/m) over a 10° wedge was computed. The first figure shows the comparison of the skin-friction coefficients predicted by the PNS code and a reacting boundary-layer code. The agreement between the two codes is excellent. In the second test problem, the hypersonic laminar flow (M = 25, Re = 150,000/m) over a 10° cone was computed. The second figure shows the comparison of the Stanton numbers predicted by the PNS and



Skin-friction comparison



Stanton-number comparison

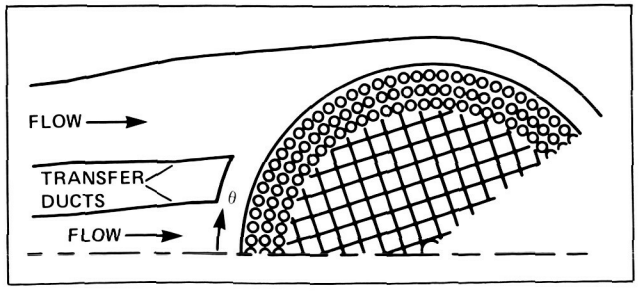
reacting boundary-layer codes. Again, the agreement between the two codes is excellent. The two test problems have demonstrated the feasibility of using PNS equations for computing chemically relaxing flow fields.

This research was supported by Ames Research Center under Grant NAG2-245 and by the Computational Fluid Dynamics Center, Iowa State University, Ames, Iowa.

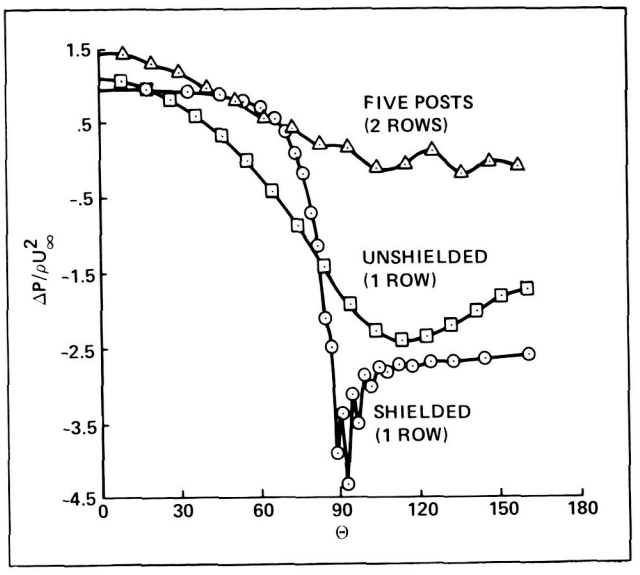
(D. Prabhu, J. Marvin, and J. Tannehill, Ext. 6192/5390/4766)

Computational Fluid Dynamics Analysis of the Liquid Oxygen Posts in the Space Shuttle Main Engine

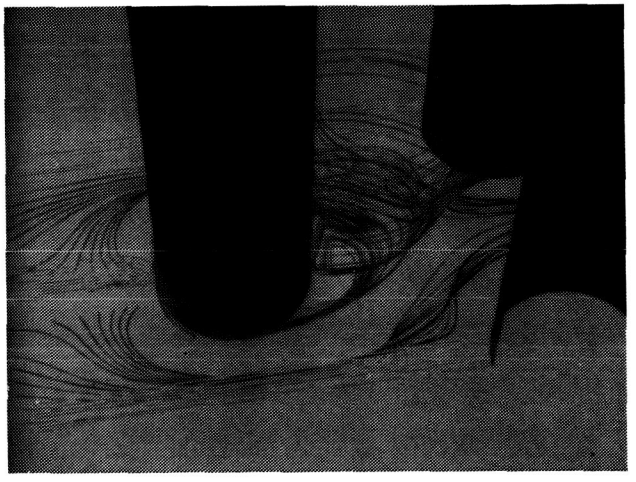
The flow around the liquid oxygen (LOX) posts in the Space Shuttle main engine (SSME) is being studied both experimentally and computationally. In the Computational Fluid Dynamics (CFD) approach, the incompressible Navier-Stokes code (INS3D) is used together with new high-level graphics programs to greatly increase the ability to analyze fuel flow through components of the SSME. Previously, INS3D has been used to analyze new designs for the hot-gas manifold (HGM), which resulted in a significant improvement in the pressure losses in the HGM. The latest version of the INS3D code uses an improved diagonalized algorithm which requires one-third the computational time to obtain a solution. The code has been used to analyze the juncture flow around a series of multiple posts mounted normal between two flat plates. The same procedure was then used to analyze single and double rows of posts in actual SSME configuration. The shielded case in the figure simulates the flow around a structurally reinforced post assembly where pairs of posts are joined by a shield.



Schematic of LOX post in the SSME



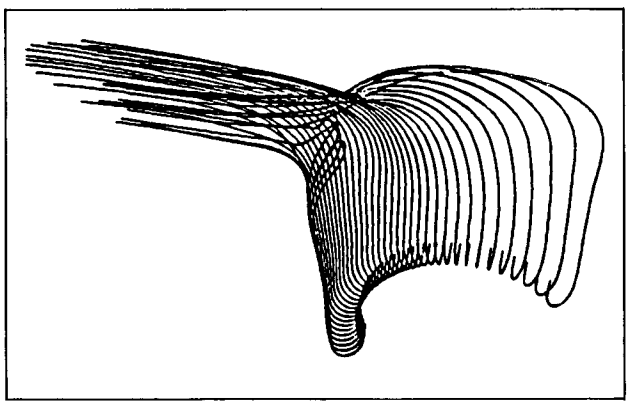
Effect of shields and secondary posts on the circumferential pressure distribution



Particle traces near the plate-post juncture for two rows of posts

The ability to analyze very large problems, and the new advances in graphics processing, has been made possible with the new hardware of the Numerical Aerodynamic Simulation (NAS) program. The NAS Cray 2 has a core memory of 256 million words, which effectively removes the memory constraint from CFD calculations. INS3D was used to obtain the first CFD results on the NAS Cray 2 when the multiple-post configuration was run using 463,000 grid points. The CFD results together with experimental data are being used in understanding the complex fluid flow in the SSME post assembly.

Additional NAS hardware include Silicon Graphics IRIS workstations which are capable of performing three-dimensional graphic transformations at the rate of 65,000 coordinates/sec. With the use of a remote graphics library, distributed graphics programs can be written utilizing the speed and massive core memory of the Cray 2 and the high-powered graphics processing of the workstation simultaneously. One such program is the Remote Interactive Particle-Tracer (RIP). Using RIP, the user on the workstation can interactively pick a starting location for a particle trace. The starting location is sent to the Cray 2 where the particle trace is computed and a graphic object is created. The object is then sent to the workstation and displayed, all in less than 1 sec. This allows the user to integrate the flow field to find some of the important physics in a very short time.



Particle traces generated by RIP showing flow through hot-gas manifold

This is a joint effort with Rocketdyne Division of Rockwell International.

(S. Rogers, D. Kwak, and M. Williams
Ext. 6740/6743)

Effect of Core Deformation on Vortex Sound

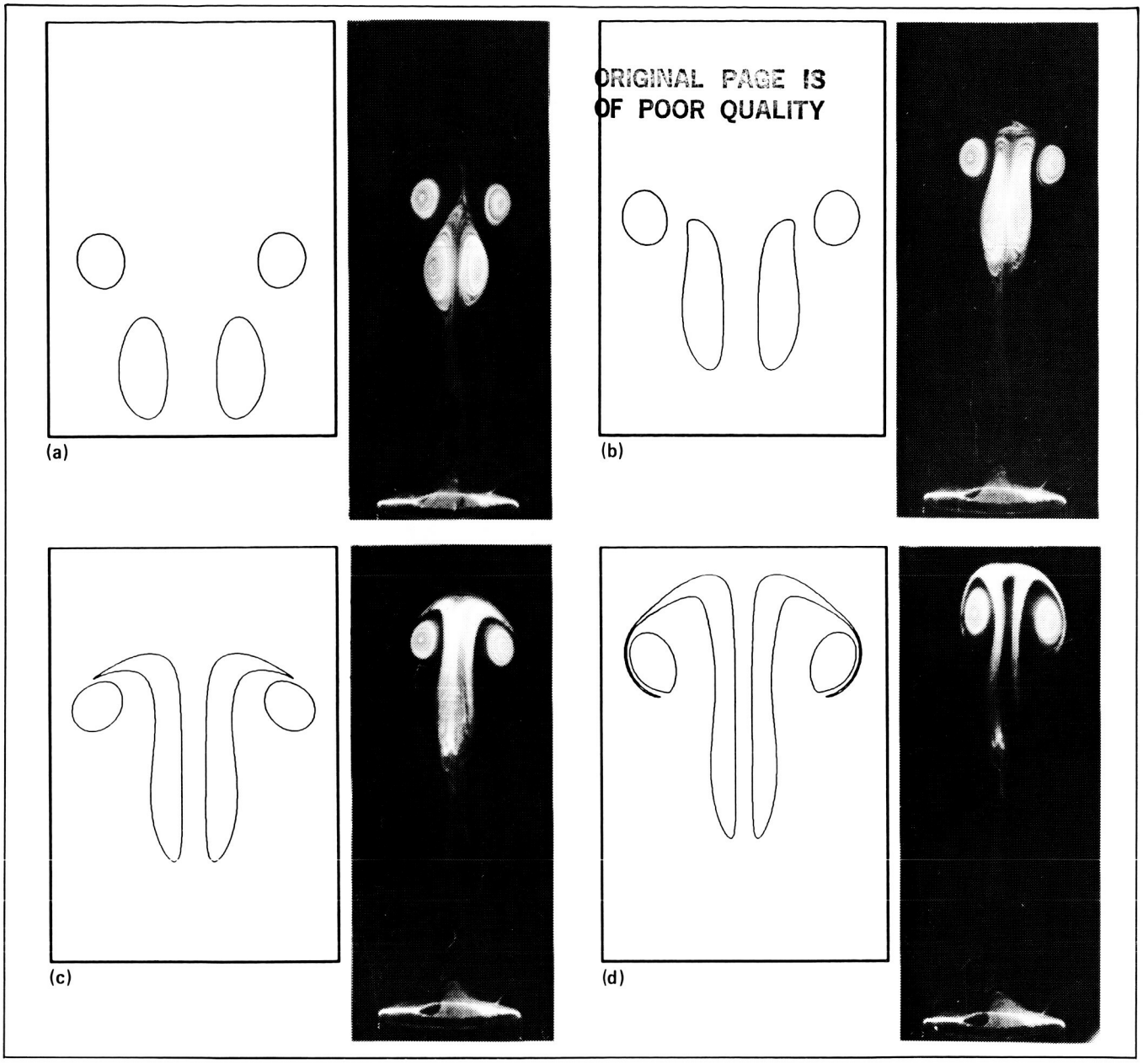
It is known from experimental evidence that a significant portion of the noise radiated from a turbulent jet comes from the interaction of vortex rings just downstream of the exit. Yet traditional models of vortex ring behavior have been unable to explain many of the observed characteristics of jet noise; for example, the presence of frequency components other than the harmonics of the frequency at which vortex rings are formed. Because these models assume the vortex cores to be thin and circular, they are unable to capture the contributions to the acoustic signal that may occur from changes in core shape.

To study these changes and their consequences for noise generation, a new numerical method has been developed for axisymmetric flow which accurately solves the inviscid equations of motion. The scheme tracks the evolution of the boundaries of the vorticity regions and hence accounts for core deformations.

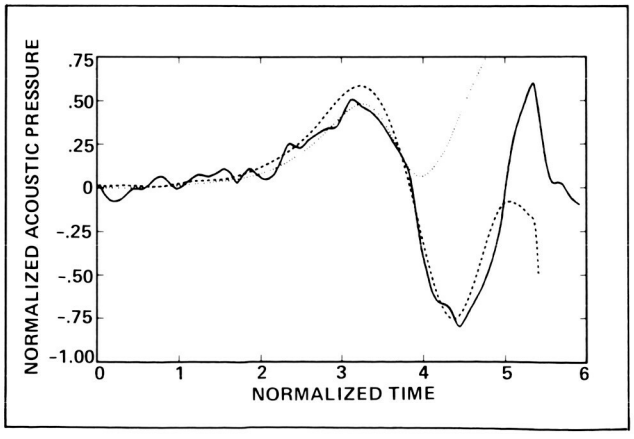
The first figure shows the simulation of two initially identical vortices in cross section and the corresponding experimental photographs. According to textbook descriptions the rear ring should slip through the leading one. Their roles having now been interchanged, the process should occur again, *ad infinitum.* However, for this case the rear vortex never passes the first; its core is instead considerably elongated and it begins to roll up around the first. Associated with this is a large dip in the acoustic signal. The classical description was found to hold for only the thinnest of cores, but here even very small pulsations of the core led to a high-frequency component of large amplitude in the acoustic signal. The total radiated energy was an order of magnitude larger than the value predicted under circular core assumptions.

The second figure shows the predicted acoustic signature resulting from the head-on collision of two vortex rings. The agreement with experiment is very good except for the final peak. The failure of the circular core model to predict the dip in the acoustic pressure in the past has been attributed to viscous effects, but in the simulations it was found to occur at the point when the cores flatten most strongly.

(K. Shariff, Ext. 6667)



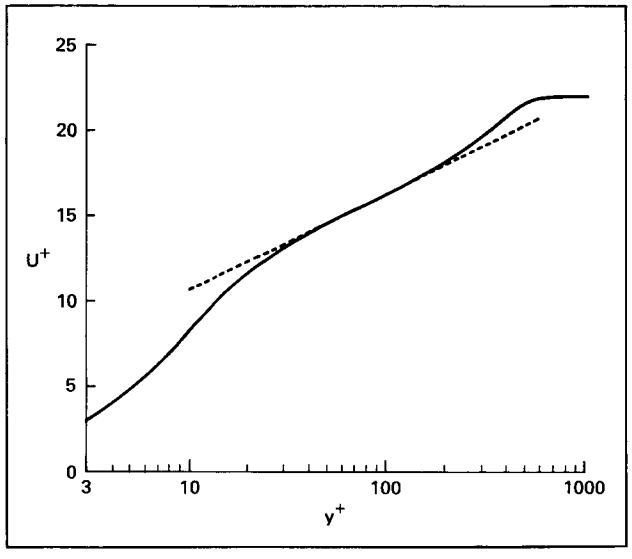
Interaction of two like signed vortex rings compared with the experiments of Oshima, et al. A section through a plane containing the axis of symmetry is shown



Acoustic signature of colliding vortex rings

Extended Log Layer in a Direct Turbulence Simulation

The turbulent boundary layer on a flat plate, with zero pressure gradient, is simulated up to $R_\theta \approx 1400$, which is approximately twice the values that had been achieved before. The three-dimensional, time-dependent, Navier-Stokes equations are solved numerically, using a spectral method with up to 8×10^6 degrees of freedom.



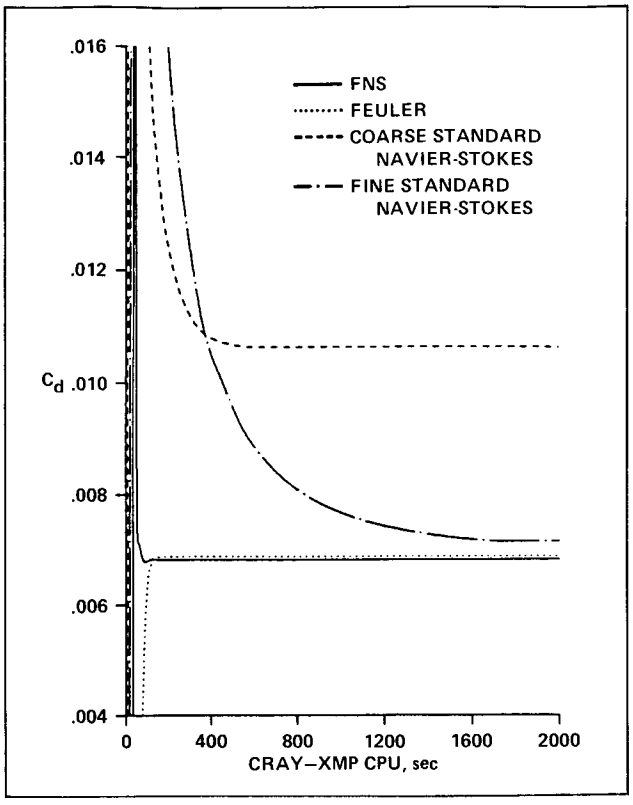
Mean-velocity profile

Periodic spanwise and streamwise conditions are applied, and a multiple-scale procedure is applied to approximate the effect of the slow streamwise growth of the boundary layer. The results are in very good general agreement with experimental results. In particular, the mean-velocity profile shows a significant logarithmic layer (the straight part of the curve, in the figure) and follows very closely the experimental value (the dashed line in the figure) $U^+ = \log(y^+)/0.41 + 5$.

(P. Spalart, Ext. 6667)

Fortified Navier-Stokes Approach

A method has been developed for improving the performance of Navier-Stokes algorithms by using fast auxiliary algorithms that solve subsets of the Navier-Stokes equations. In this approach (the Fortified Navier-Stokes approach) solutions to the subset equations are used to add forcing terms to the Navier-Stokes algorithm in the appropriate flow regions. The payoff of this scheme is an improvement of both the efficiency and the accuracy of a given Navier-Stokes algorithm.



Drag coefficient versus Cray-XMP processor time for the separated flow over the upper-surface of a three-dimensional winglike configuration

For example, by fortifying a Navier-Stokes algorithm with an efficient boundary-layer algorithm, accurate drag predictions are obtained with about an order-of-magnitude savings in computer time. Specifically, the drag coefficient history versus Cray-XMP cpu time for the separated flow over the upper surface of a three-dimensional winglike configuration is presented in the figure. The flow was computed using a standard thin-layer Navier-Stokes algorithm on both a coarse and a fine mesh, with a Fortified Navier-Stokes algorithm, and with a Fortified Euler algorithm. The coarse-mesh standard Navier-Stokes computation is not accurate (compared to the fine-mesh Navier-Stokes result). However, the Fortified Navier-Stokes/Euler algorithms yield essentially the same drag levels as the fine mesh standard Navier-Stokes algorithm with at least an order-of-magnitude savings in computer time.

(W. Van Dalsem, Ext. 6741)

Interactive Viewing Window into the Cray 2 Computer

A "viewing window" into the Cray 2 computer has been created, allowing a scientist with the Silicon Graphics Iris workstation to interactively view calculations on the Cray 2. The three-dimensional (3-D) dynamic image (display list) is created by the Cray, and the scientist's view of the image (the transformation and projection of the 3-D display list onto the two-dimensional (2-D) screen) is dynamically created by the Iris workstation. The scientist uses the input devices on the workstation for interactively controlling both the image creation (by the Cray 2) and the desired scene-viewing position (transformation and projection by the Iris).

An example of the use of this capability is for analyzing flow-field solutions. The scientists can interactively select points in space to start flow-field particle tracers and then watch the dynamics of the tracers while simultaneously changing their viewing positions to get the best view of the dynamics. They can interactively add or delete particle tracers as desired to improve the understanding of the flow.

This capability was accomplished by 1) the development of a high-bandwidth connection between the Cray 2 computer and the Silicon Graphics Iris workstation, 2) the development of process-to-process communication programs within the Cray 2 computer and the Iris workstation, and 3) the integration of these programs into the "Plot 3-D" flow-field visualization software previously developed by Pieter Buning at Ames.

(V. Watson, Ext. 6421)

System for Automated Creation of Videotapes or 16-mm Movies of Computer-Generated Graphics

A system has been developed for the automated creation of videotapes or 16-mm movies of computer graphics generated on the Silicon Graphics Iris workstation. With this program, a scientist can interactively create scenarios of three-dimensional (3-D) image dynamics (sequences of 3-D display lists) with simultaneous changes in viewing positions (sequences of transformations and projections of the 3-D image onto the two-dimensional screen) and have the scenarios automatically recorded on videotape or 16-mm movies. The system provides automatic "tweening" for smooth transitions between user selected viewing positions.

(V. Watson, Ext. 6421)

Vortex Flows on Bodies of Revolution

The complex flow field generated by a slender body of revolution at high angle of attack is presently being investigated using a combined computational and experimental approach. The objective of this study is to gain further insight into the mechanisms which affect the growth and stability of the vortical flow.

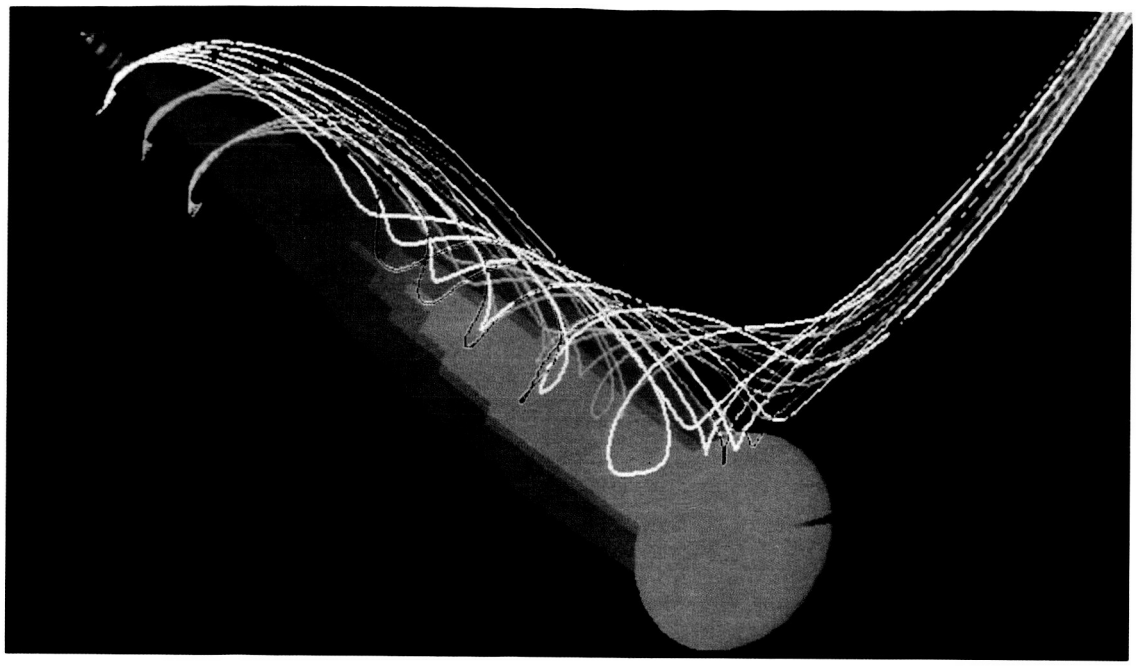
On the lee side of a slender body of revolution (e.g., aircraft fuselage) at moderate incidence, two longitudinal primary vortices form and assume a symmetric orientation. At a critical angle of attack, a disturbance can cause a dramatic change in the orientation of the primary vortices to a new, stable, asymmetric state. Often this asymmetric flow generates unwanted side forces which can cause a flight vehicle to become uncontrollable.

The mechanisms which cause the flow to become asymmetric are not currently understood. Several hypotheses have been formulated based on the impulsive flow analogy which relates the three-dimensional (3-D) steady flow past a pointed slender body to the two-dimensional (2-D) unsteady flow around a circular cylinder. So far, the analogy has not been fully proven.

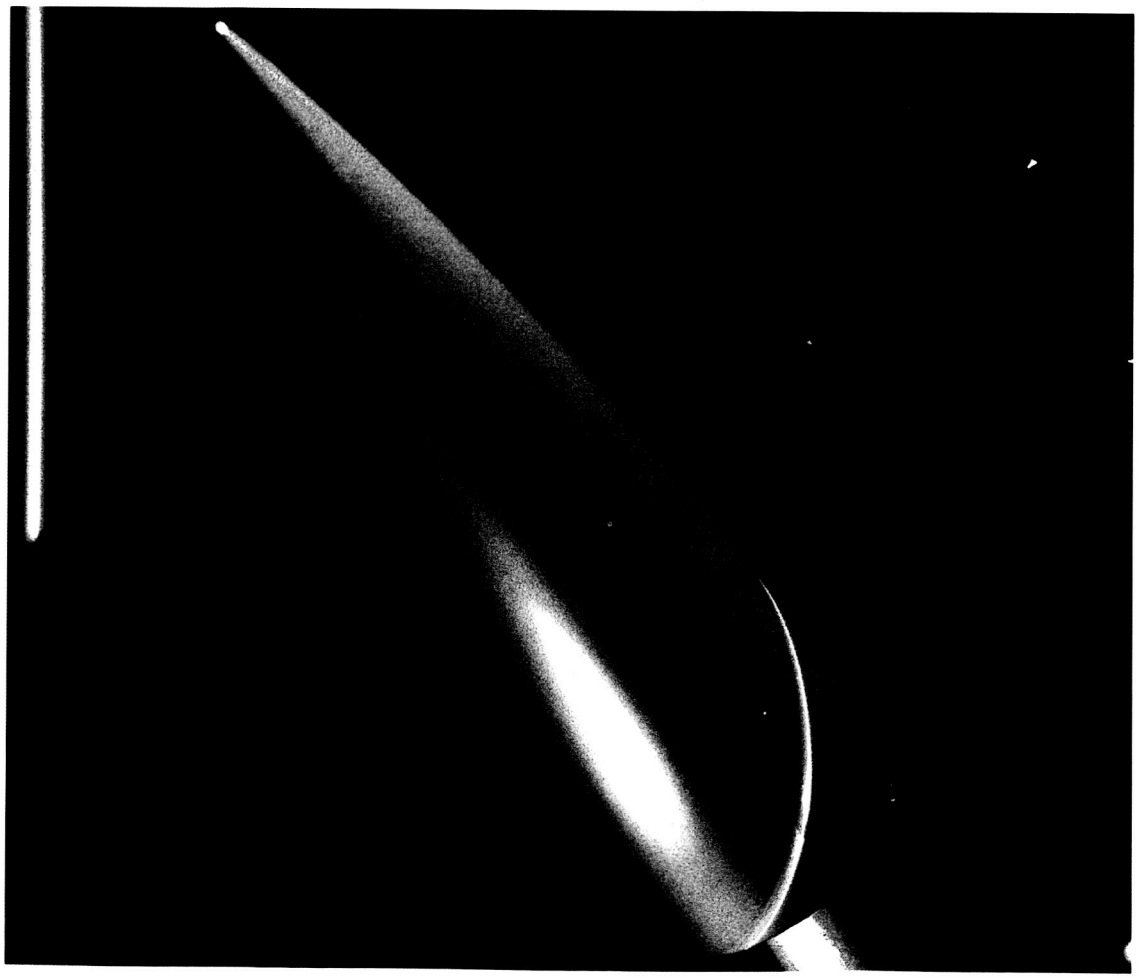
Smoke-flow visualization of the flow past an ogive-cylinder at 45° angle of attack is shown. An array of 60 smoke filaments produced from a rake located upstream of the model impinge on the centerline of the ogive cylinder. Some of the filaments which pass above the tip are stretched and entrained by the primary vortices as the flow develops along the body. Laser sheet illumination of the cross-flow plane clearly shows the steady longitudinal vortices which form on the lee side of this body.

A companion 3-D, incompressible Navier-Stokes computation (INS3D) of the same configuration, but at lower Reynolds number, is also presented. Five arrays of particles are released in the windward boundary layer. The path lines formed by these particles show the initial rollup of half of the symmetric vortex pair. The experimental and computational results show promising qualitative agreement.

(G. Zilliac, Ext. 4142)



3-D Navier-Stokes computation



Smoke flow visualization

Properties of Molecules and Clusters

The determination of the properties of molecules and atomic clusters from calculations continues to produce important results for predicting and understanding the properties of matter. Studies have been completed on various transition metal triatomic molecules (Ag_3, Au_3, $AgCu_2$, Cu_3, Ni_3, Sc_3, and Y_3) which have led to a detailed understanding of the metal-metal chemical bonds for simple systems. Calculations have also been completed on transition metal oxides (ScO, VO), sulfides (ScS, VS), and hydrides (ScH, YH, TiH, VH) to assist in understanding the metal-gas bonds. Larger, more approximate, calculations have been performed on clusters of Be, Ni, Cu, and Al to investigate the transition of material properties from clusters to bulk. Studies of organometallic compounds such as have been completed to describe the metal-metal and metal-ligand bonding, balance these systems.

A computational research program to investigate the details of polymer structure and to study the relationship between the molecular structure and observed properties of polymeric materials is in progress. The following molecular properties can be computed by using *ab initio* quantum mechanical methods: conformational geometries and energies, infrared vibrational spectra, energy barriers for internal rotation (activation energies for conversion between conformers), and optical anisotropies. The polymers are represented by small oligomeric models.

During the past year calculations were completed for the conformational energetics of diphenyl carbonate and 2,2-diphenyl propane — model compounds for bisphenol-A polycarbonate. In particular, we have identified the minimum energy pathway for the interconversion of trans-cis to trans-trans conformers. The results of these calculations shed light on the nature of the large-amplitude chain motions occurring at low temperatures which give rise to the high-impact strength of this glassy polymer. Calculations of the vibrational force fields and infrared spectra of polycarbonates and polyimides have also been completed as has a computational study of the optical anistropy changes in polymethyl methacrylate induced by changes in conformation.

(D. Cooper and R. Jaffe, Ext. 6213/6458)

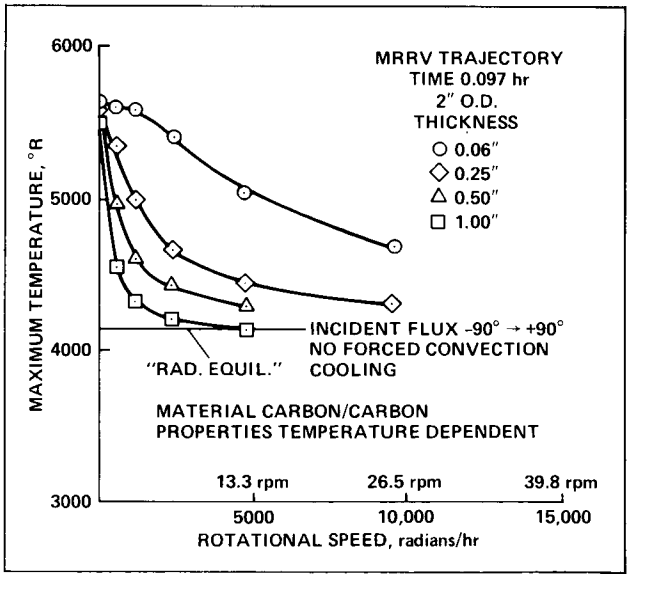
A New Concept for Thermal Protection of Leading Edges for Hypersonic Vehicles

The most demanding thermal protection problem for advanced hypersonic flight vehicles will be that encountered by the leading edges and nose caps. Ames Research Center has defined and evaluated a novel approach to solving this problem: the spinning, leading-edge concept. This concept significantly lowers the structural temperature at the stagnation region by using a rotating element to provide added heat rejection through a combination of solid conduction, reradiation, and convective cooling.

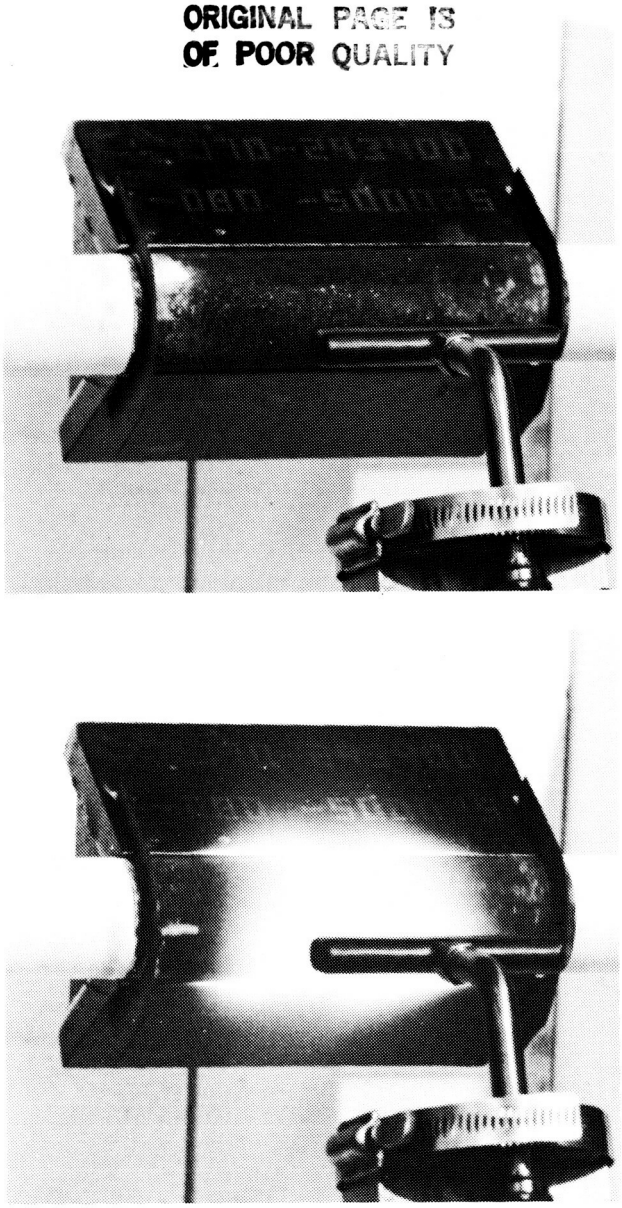
Initial analytical studies show that the net heat flux in the stagnation region can be lowered by more than a factor of three. Surface temperatures can be lowered from 5000°F to 3600°F at a stagnation-point heat flux of 450 BTU/ft^2-sec.

A prototype model was built using a silicon carbide tube as the spinning element and building simulated structure from reusable surface insulation (RSI). The model was tested in an oxy-hydrogen flame heating environment. Experimental results verified the analytical predictions. A prototype is now being designed and built, using an air-bearing approach to suspend and spin the leading edge, to determine the performance in an arc-plasma test that will simulate the aerothermal environment for the aerospace plane.

(H. Goldstein Ext. 6103)



Effect of rotation rate on stagnation temperature



Spinning leading edge in oxygen hydrogen torch test

Properties of Nonequilibrium Air in the Shock Layer Surrounding the National Aerospace Plane and Aeroassisted Orbital Transfer Vehicles

The shock layers formed around the National Aerospace Plane (NASP) during both the ascent and descent phases of its flight trajectory, and in front of the aeroassisted orbital transfer vehicle (AOTV) during the aerobraking maneuver will be characterized by nonequilibrium distributions in the chemical composition and energy owing to the low ambient gas density. Rotational and translational energy distributions will probably be in thermal equilibrium. However, there will not be sufficient atomic and molecular collisions for vibrational energy and electronic excitation distributions to be equilibrated. In addition, the chemical composition will be governed by the finite rate chemistry rather than by chemical equilibrium. For the AOTV, a large radiative heat load is expected as a result of these nonequilibrium conditions.

Computational fluid dynamics calculations of the flow field properties for these vehicles must include real gas, finite-rate chemistry, and thermal nonequilibrium effects if they are to achieve realistic and accurate solutions. The existing chemical and physical properties data base for high-temperature air is not adequate for this task. However, the first-principles quantum chemistry calculations being carried out at Ames Research Center are capable of providing accurate reaction rate constants and cross sections for conditions of temperature and pressure that are not amenable to experimental study.

For NASP, the shock-layer temperatures will be high enough to promote the dissociation of molecular oxygen. This will initiate an exchange reaction cycle which will lead to the formation of an excess of NO. The rates of these reactions under the high-temperature, nonequilibrium conditions are not well known, but can be computed using scattering theory provided that the interaction energies between the colliding atoms and molecules are known. To this end, first-principles calculations of the ground electronic state potential energy surfaces for the $N_2 + 0 \Rightarrow N + NO$ and $O_2 + N \Rightarrow NO + O$ reactions have been carried out. These surfaces represent the interaction energies of the N-N-O and N-O-O systems, respectively, for all accessible geometrical arrangements of the atoms. Classical scattering theory calculations to determine the actual rate constants for these reactions are in progress.

For AOTV, the shock-layer temperatures will be considerably higher, and both ionization and nitrogen dissociation are expected to occur. Potential energy surfaces for the collisional dissociation of nitrogen have been calculated and will be used for classical scattering theory studies of dissociation and vibrational

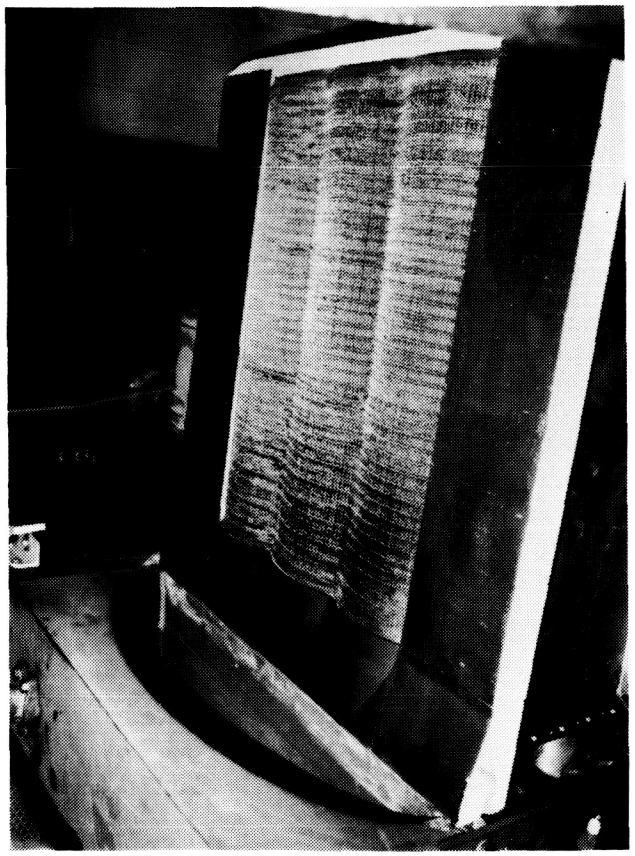
excitation/deexcitation processes. In addition, the electronic excitation of N_2 caused by collisions with electrons is being studied.

As data are accumulated from these computational studies, they are recast in a suitable form for inclusion in the flow field models and made available to others in the aerothermodynamics community.

(R. Jaffe and D. Cooper, Ext. 6458/6213)

Advanced Thermal Protection System for Aerobraked Orbital Transfer Vehicles

A number of vehicle concepts are under study by NASA for the structure and thermal protection system of the aerobraked orbital transfer vehicle (AOTV). Several concepts utilize a flexible heat shield material developed at Ames Research Center called tailorable advanced blanket insulation (TABI).



Flexible ceramic blanket insulation on ballute test article installed in arc heater prior to testing

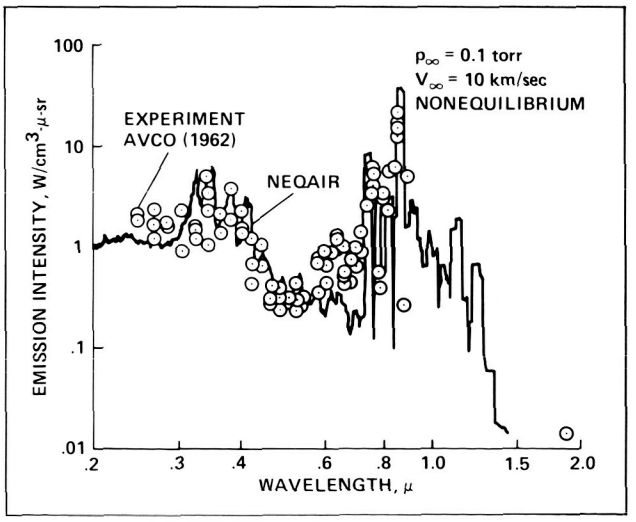
In a joint research program, a full-scale model representing a segment of a "ballute" AOTV thermal protection system was fabricated and tested. The model was designed by Boeing and was built by Goodyear using the TABI material developed by Ames. The TABI materials were woven by Woven Structures, Inc. Ames performed the arc plasma tests in the Ames 60-MW Interaction Heating Facility.

This test demonstrated for the first time that a flexible heat shield structure can be built from both aluminoborosilicate and silicon carbide materials, and that such a structure would survive multiple simulated reentry heating cycles at heat fluxes ranging from 7.5 BTU/ft^2-sec for the aluminoborosilicate TABI to in excess of 20 BTU/ft^2-sec for the silicon carbide TABI.

(W. Love, P. Sawko, and H. Goldstein, Ext. 5370/6103)

Computation of Thermo-Chemical Nonequilibrium Flow in Nitrogen and Air

The development and validation of a computer program to calculate the flow of nitrogen and air in thermal and chemical nonequilibrium is a first step toward the longer-range goal of predicting multidimensional flow fields in nonequilibrium air and hydrogen-air combustion processes. This predictive capability is critical to



Comparison between calculated and measured spectra for nonequilibrium

designing the protective heat shield for the aeroassisted orbital transfer vehicle (AOTV) for which radiation heating loads are expected to be severe, and to analyzing scramjet engine performance for the airbreathing propulsion system of the National Aerospace Plane.

The one-dimensional viscous flow-field equations (Navier-Stokes and chemical species), with physically realistic thermo-chemical nonequilibrium gas models, are solved fully coupled for flow fields corresponding to ground-based experiments. Observable radiative properties are computed for these flows for dissociating and ionizing nitrogen and air and the results compared with existing experimental data.

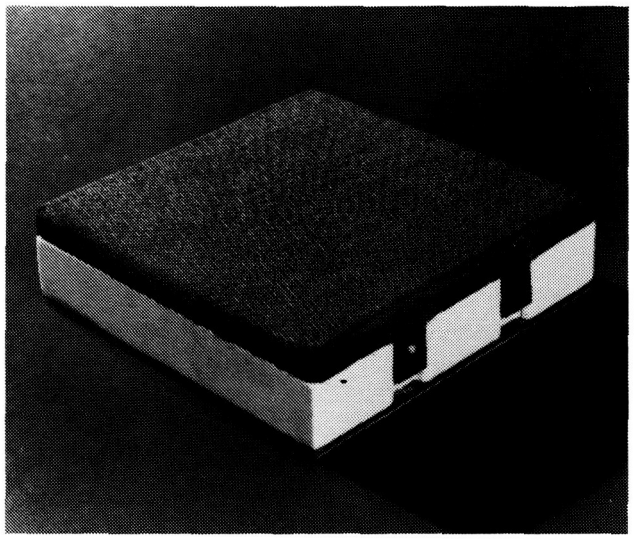
A computer program identified as the shock tube radiation program (STRAP) has been developed which computes one-dimensional viscous flows of nitrogen and air in a constant-area duct. By improving existing theories and by introducing several innovations, differences between the translational and rotational temperature and the vibrational and electron-electronic temperature are considered, as are chemical reactions whose rates depend on these two temperatures. The computed nonequilibrium thermodynamic properties have been analyzed using the nonequilibrium air radiation (NEQAIR) program to determine the spectral radiation characteristics. The resulting radiation characteristics are compared with available experimental data. Good agreement is observed between the experimental and the present theoretical data, thus validating the computations and the computer code.

The work validates the basic kinetic two-temperature model and the algorithm for computing such chemically reacting flows. The technique can be extended to gases of more complex chemistry and to more complicated multidimensional flows.

(C. Park, Ext. 5394)

Development of Ceramic/Ceramic Composite Materials for High-Temperature Structure and Thermal Protection Applications

A new class of ceramic/ceramic composite materials is being developed for aerospace vehicle structural and thermal protection applications. These composite materials have greatly improved mechanical strength and toughness properties compared to the fibrous ceramic materials currently in use as the Space Shuttle heat shield. They have potential as structural components as well as load-carrying outer surfaces in advanced thermal protection systems for vehicles such as the National Aerospace Plane.



Toughened outer surface "top hat" reuseable surface insulation

As part of the development effort to investigate fabrication techniques for these ceramic/ceramic materials, a single-layer composite made of aluminoborosilicate AB312 plain-weave fabric and silicon carbide deposited in depth with a chemical vapor-deposition process has been made in a "top-hat" configuration (see figure). This top-hat section was used as the outer skin of a reusable thermal protection system with rigid fibrous refractory composite insulation (FRCI) and flexible Nextel materials as insulative backing. The thermal performance of this system in arc plasma tests was comparable to an LI-900 system, but had an impact resistance 20 times higher than that for the older LI-900 system used as the Space Shuttle Orbiter heat shield.

(S. Riccitiello and H. Goldstein, Ext. 6080/6103)

Space Research

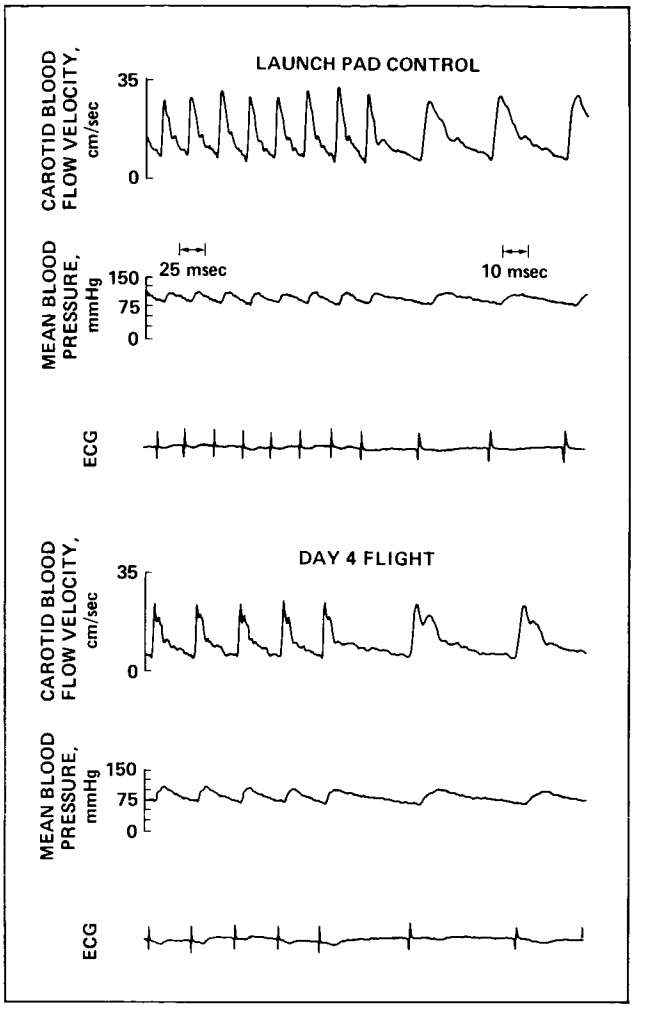
Joint U.S./U.S.S.R. Cosmos Spaceflight Experiment

The completion of the Cosmos 1667 mission (flown July 10-17, 1985) has allowed U.S. investigators another opportunity (the first having been Cosmos 1514 flown December 14-19, 1983) to obtain data on pressure and flow to the head in nonhuman primates during extended spaceflight. One of two rhesus monkeys (*Macaca mulatta*) flown aboard Cosmos 1667 (Gordyy, 5 yr old, 4 kgm) was instrumented 62 days before flight with a transducer developed in the Cardiovascular Research Laboratory at Ames Research Center. Blood pressure was sensed by a diaphragm strain gage resistance transducer and blood flow was sensed using ultrasonic crystals. Flight information was compared with results from a synchronous control experiment using the flight animal (all conditions identical except weightlessness) 1 mo later (August 9-16, 1985). Data were recorded daily for 5 min every 30 min, 2400 to 0800 hr and for 5 min every 2 hr, 0800 to 2400 hr. These data (recorded on a Soviet analog-type recorder) were transferred to U.S. Equipment during the first 3 wk of October 1985 and were subsequently analyzed at Ames. Two Soviet investigators (principal scientist and engineer for this project) visited Ames January 10-22, 1986, to discuss data format. They presented results obtained by other investigators on this flight and invited U.S. participation in a joint symposium on this activity in Moscow June 19-24, 1986.

The hemodynamic changes in the flight animal while in orbit and on the launch pad are shown in the accompanying figure. The average rate decreased over the course of the flight (142 ±3.2 bpm [M ±SE], Day 1 to 116 ±2.7 bpm Day 6 [$p < 0.01$]) which did not occur during the synchronous experiment (daily mean ranged from 131 to 143 bpm). The mean blood flow velocity during flight (35 ±2 cm/sec) was significantly lower ($p < 0.01$) than during the ground-based control test 43 ±1 cm/sec). The overall changes, including a lower heart rate and flow, are interpreted to indicate adaptive changes to the headward fluid shift known to regularly occur with spaceflight and the associated hypometabolic state of weightlessness.

These experiments have allowed close interaction between U.S. and U.S.S.R. investigators, opportunities to visit and observe laboratory procedures for the two countries, and opportunities to initiate and conduct spaceflight studies using an animal model closely resembling man.

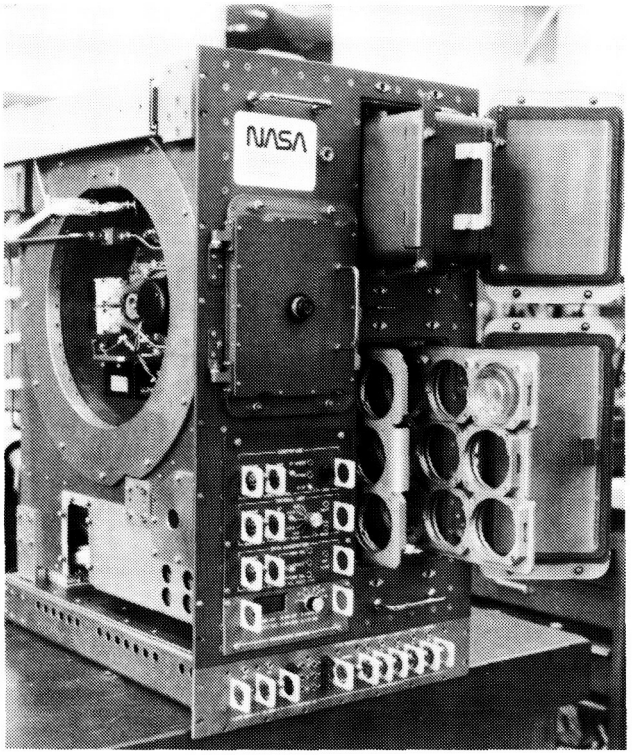
(H. Sandler, Ext. 5745)



Hemodynamic changes in the flight animal

Ames Research Center Prepares Spacelab Payloads

Several pieces of hardware have been developed to support biological payloads, with flights scheduled on missions managed by Marshall Space Flight Center. The Frog Environmental Unit (FEU) which was developed at Ames and scheduled to be flown on Spacelab J (SL-J), is a module which provides environmental support to frogs and developing frog eggs, and includes a 1-g centrifuge which simulates Earth gravity for developing frog embryos. This unit has completed



Frog embryology unit

critical design review and fabrication, but has not yet been tested. It will be used to test the hypothesis that frog-egg development is a gravity-dependent event.

The Gravitational Plant Physiology Facility, to be flown on the International Microgravity Laboratory-1 (IML-1), is a module which supports investigations on the effect of gravity on geotropism (gravity-directed growth), phototropism (light-directed growth), and nutation (spontaneous movement). This facility, consisting of a central control unit, 1-g culture rotors, variable-g test rotors, plant-holding compartment, mesocotyl suppression box, video cameras and recorders, and a recording and (blue light) stimulus chamber, was developed by the University of Pennsylvania under contract to Ames. It has completed critical design review and fabrication and acceptance testing, and is currently being modified to meet structural requirements. Also scheduled to be flown on IML-1 are specialized chambers, developed at Ames, supporting investigations on nematodes, yeast cultures and chondrocyte cell cultures. These chambers are currently prototype hardware items being evaluated against biocompatibility and functional requirements prior to flight item fabrication.

Supporting an Atmospheric Laboratory for Applications and Science (ATLAS) mission are several pieces of spaceflight hardware. A plant container, capable of supporting the growth of 62 plant seedlings in the dark for growth hormone determination has completed all testing and is ready for flight. Also ready is a neurospora growth package which allows for observation of the organism and marking of growth patterns for circadian rhythm investigations without disturbing the organism. A cell culture container, capable of supporting the growth of pituitary cells in 160 tubes without exhausting media, oxygen, or waste control has been qualified for flight to determine growth hormone production. A mini-temperature recorder (1 X 2 X 4 in.) similar in design to the Cosmos series recorders has also been developed for this mission.

(P. Callahan, Ext. 6046)

Ames Research Center SLS-1 Payload

The Ames Research Center Payload for the Spacelab Life Sciences One (SLS-1) Mission has been reconfigured to include three rodent animal enclosure modules (AEMs) and a jellyfish experiment. The AEMs will house 14 rats and will enable most of the previously planned scientific experiments to be performed, although with only preflight and postflight interaction with the animals. A rodent experiment verification test has been carried out with project and Principal Investigator participation, successfully demonstrating the feasibility of experiment operations. An AEM hardware critical design review and prototype unit fabrication were completed. Development testing and AEM flight unit fabrication is under way. Development of the jellyfish experiment continues, including specimen containment hardware prototype fabrication and experiment timeline planning.

A particulate containment/demonstration test (PCT) has also been added to the payload to enable in-flight verification of a redesigned rodent research animal holding facility (RAHF) cage. This test will demonstrate the adequacy of the redesign concepts incorporated into the hardware, resulting from detailed investigation of the particulate release problems experienced with the RAHFs during the Spacelab-3 Mission. RAHF airflows through and around the cage will be represented by an airflow simulator to provide a close

simulation of the RAHF/cage environment during in-orbit operations. The PCT includes tasks to verify satisfactory operation of activities between the RAHF and the general purpose work station (GPWS). It also includes a test to verify satisfactory containment of the GPWS, which is then used to perform the cage containment tests. Development and prototype fabrication of the PCT hardware and PCT timeline planning is under way.

Modifications have been incorporated into the GPWS to accommodate in-orbit activities and to provide an increased level of positive containment of particulates and fluids during all operational modes. Modifications have also been embodied to provide current limiting at the electrical interface during startup. Functional and electromagnetic compatibility/interference testing has been performed to verify the modifications.

(B. Dalton, Ext. 6188)

Landslide Prediction

Landslides and debris flows are geologic events that all too often cause significant loss of life and property. Scientists from the U.S. Geological Survey (USGS) are working at Ames Research Center on ways to build a framework for new predictive models.

Significant progress is expected to be made by using a geographic information system (GIS) capable of correlating multivariate data. Landslides are correlated with soil type, topographic slope, and rainfall intensity. Underlying geology, physiography, vegetation, and other factors are also important variables. What is not known is the total effect and importance of each of these factors.

To learn more about those effects and to create a predictive model, scientists from the USGS assembled data already in digital form from past efforts by them and the Association of Bay Area Governments. They then used these data sets, together with Landsat thematic mapper digital imagery, within a GIS accessible to them at Ames.

Within the GIS, based on a raster data structure, values for each of the variables (data layers) were coded for a matrix of 30-m grid cells covering San Mateo County. A technique known as logistic regression analysis (LOGIT) was used to determine the characteristics of the variables. Training data based upon both continuous (thematic mapper) and discrete (geologic units) information was used to estimate the coefficients for the logistic regression. These coefficients were used to classify the entire matrix of grid cells. Each was assigned a value based on the probability of that grid cell belonging to the known class of debris sites. Correspondence was high between areas of the resulting map showing high probability and actual occurrence of slides.

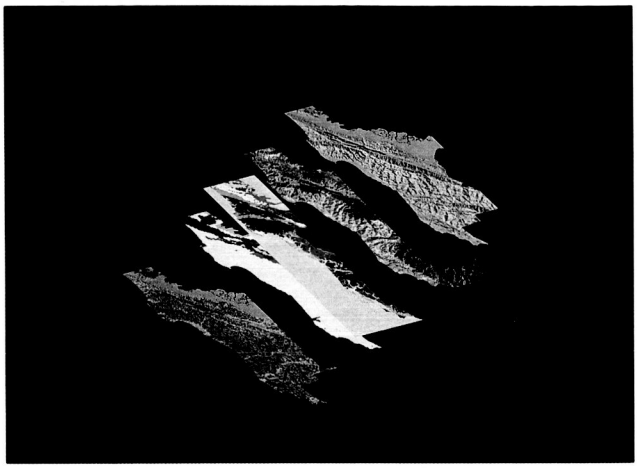


Figure symbolizing the interaction of four multivariate data layers in a Geographic Information System and the resulting landslide probability map output by the predictive model that was created

The study so far has shown that a GIS can be used to predict the occurrence of geologic hazards based on the complex interaction of mapped variables. After further refinements, it is expected that the model will be tested in other areas where more limited data exist. The hope is that techniques can be developed to tag areas of geologic risk and that this information will be used to improve land use planning decisions.

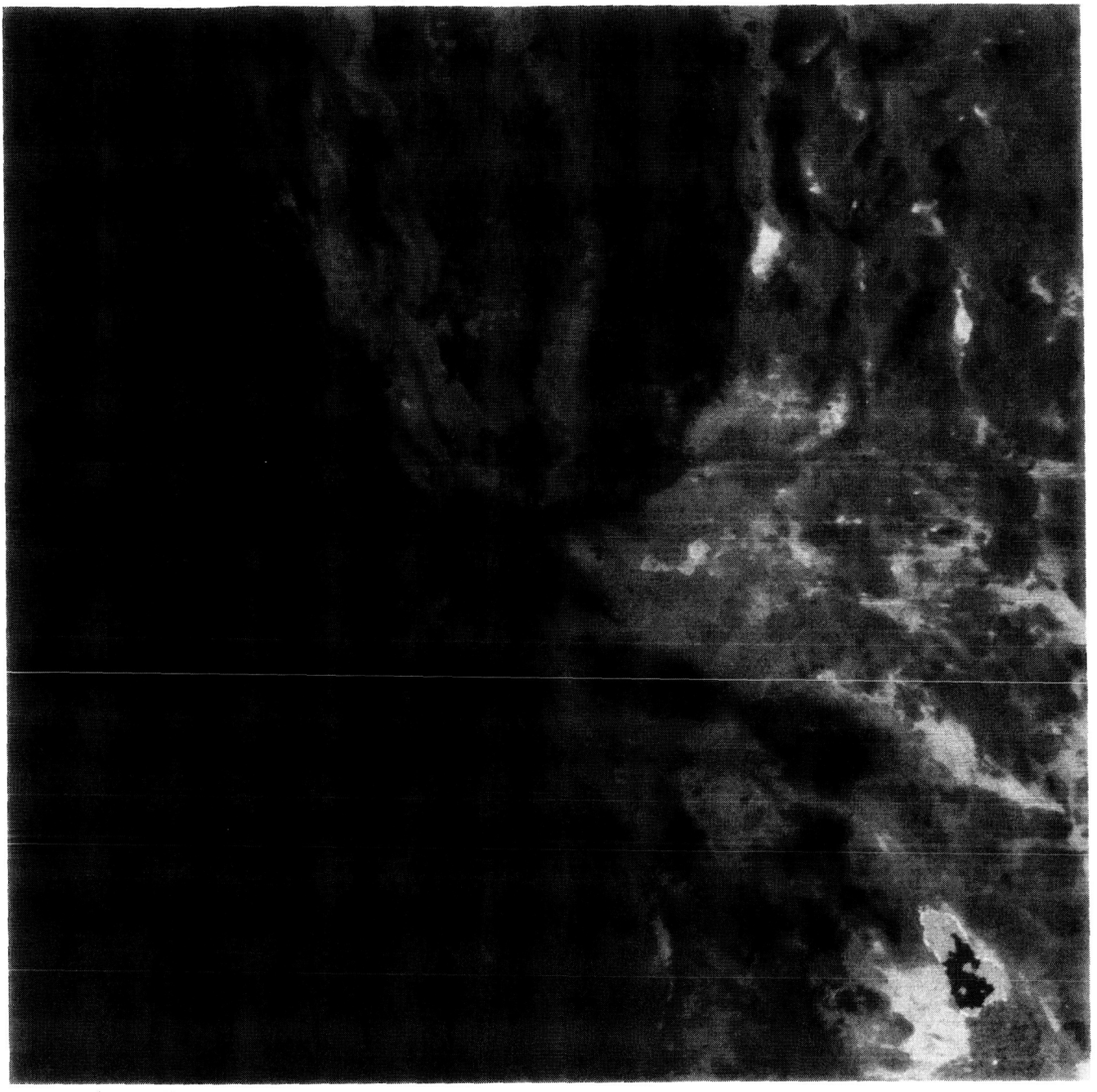
(W. Acevedo, Ext. 5299)

Global Effects of Biomass Combustion

Research into the effects of biomass combustion on biogeochemical cycling, based on the interaction of fire variables, biological factors, and nutrient cycling, is one of the current activities of the Ecosystem Science and Technology Branch at Ames Research Center. This project is a joint activity between Ames and the U.S. Forest Service.

Daedalus scanner imagery collected over the Ojai (Wheeler Springs) California Fire on July 2, 1985. The scene is composed of spectral information from the mid-infrared to the thermal infrared portion of the EM spectrum. The active fire fronts can be seen as bright areas. Temperature calculations are highlighted in green and yellow

The basic tenet of this research integrates *in situ* field measurements, nutrient cycling monitoring, and remote-sensing instrumentation to test three hypotheses: (1) that fire periodicity and intensity play major roles along with vegetation and climate in determining nutrient movement caused by biomass combustion; (2) that fire behavior is predictable, given vegetation, climate, and topography; and (3) that fire detection, intensity, and post-fire characteristics can be quantified with remote-sensing instrumentation.



National Oceanic and Atmospheric Administration, Advanced Very High Resolution Radiometer sensor collected scene of Southern California. This scene was imaged at 1:54 p.m. PST, and shows two major fires occurring along the coast range. The topmost fire is the Rat Creek burn and the fire to the south is the Ojai burn. This image is composed of thermal infrared and near infrared wavelength bands

The remote-sensing information can then be a data layer in models predicting the effects of biomass combustion on nutrient cycling.

To derive global estimates of biomass combustion and the effects on biogeochemical cycling and tropospheric chemistry, some foundation of sensor technology and fire characterization is needed.

During the 1985 summer wildfire season in California, data from a Daedalus Scanner (12-channel, visible to thermal spectral data) were

collected using a NASA-Ames U-2C aircraft over numerous wildfires, one of which, the Ojai (Wheeler Springs) fire, is shown here. Collected on July 2 at 2:55 p.m. PST, the imagery was extremely valuable for determining specific fire and fire-related characteristics, such as fire intensity, rate of spread, plume composition and volume, and soil cool-down behind the fire line. All of these variables significantly contribute to biogeochemical cycling. The other image is a scene collected the same day at 9:30 a.m. PST from the National Oceanographic and Atmospheric Administration Advanced Very High Resolution Radiometer (AVHRR) satellite system. This partial scene which covers the southern half of California shows the smoke plume from the Ojai fire being carried south over the ocean and then east into the Los Angeles basin, contributing to the area's chronic air pollution.

By combining similar information from these and many other data sources, the research team envisions providing comprehensive estimations of annual global biomass emissions, thereby increasing the scientific community's knowledge of fire-related involvement in biogeochemical cycling.

(V. Ambrosia and J. Brass, Ext. 6184/5232)

Cycling of the Biogenic Elements on Mars

Considerable evidence exists which suggests that at some time in the past conditions on Mars were quite different than they are today. It has been shown that the past geochemical and climatic regimes of Mars may have been favorable to the origin of life, i.e., warmer temperatures than occur today, liquid water, and abundant supplies of C, H. O, P, and S.

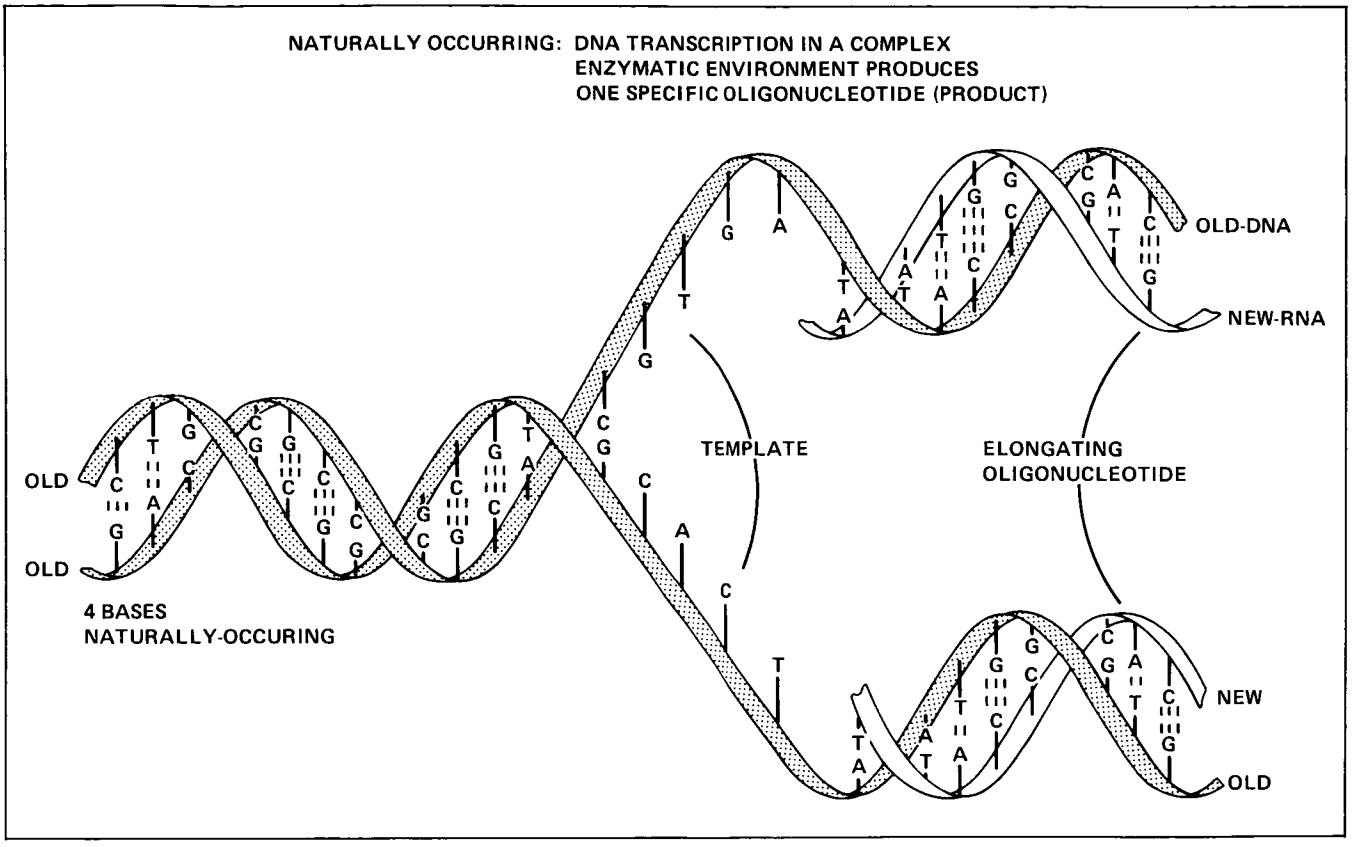
A major problem one encounters when attempting to postulate evolution of an ancient Martian biota is that of nitrogen limitation and cycling rates. The present level of nitrogen in the Martian atmosphere is approximately 0.2 mb, which is significantly lower than the 800 mb found on Earth. Furthermore, there is no direct evidence for the existence of nitrogen compounds in the Martian soil, although the question has clearly not been resolved satisfactorily. Geology studies alone are insufficient, so exobiological research must play a role in answering these types of questions about Mars. At the low partical pressure of nitrogen found on Mars, it is unknown whether biological nitrogen fixation can occur. Models based on the current isotopic ratio of nitrogen on Mars suggest that in the past the concentration of nitrogen in the Martian atmosphere was considerably higher than it is today, i.e., 18 mb, which is considerably lower than that found on Earth during the same period. Since a major apparent difference between Earth and Mars is the comparative abundance of nitrogen, it can be hypothesized that nitrogen may have played a key role in the early evolution of life on Mars and possibly in its subsequent extinction. However, preliminary data obtained in our laboratory at Ames Research Center suggest that at least free-living nitrogen-fixing organisms belonging to the genera *Azomonas, Beijerinckia,* and *Azotobacter* have the ability to fix nitrogen at a partial pressure of 10 mb. However, on Earth even with 800 mb of nitrogen, many ecosystems are nitrogen-limited. We are carrying this study further by comparing and analyzing N-cycling in different ecosystems, and determining the biotic vs. abiotic constraints of N-cycling in an N-poor and N-rich environment. All of these data will be used to develop models that will allow us to speculate on the probability if it were ever possible on Mars for a biotic system to play a role in the nitrogen cycle, or if the major force was always abiotic.

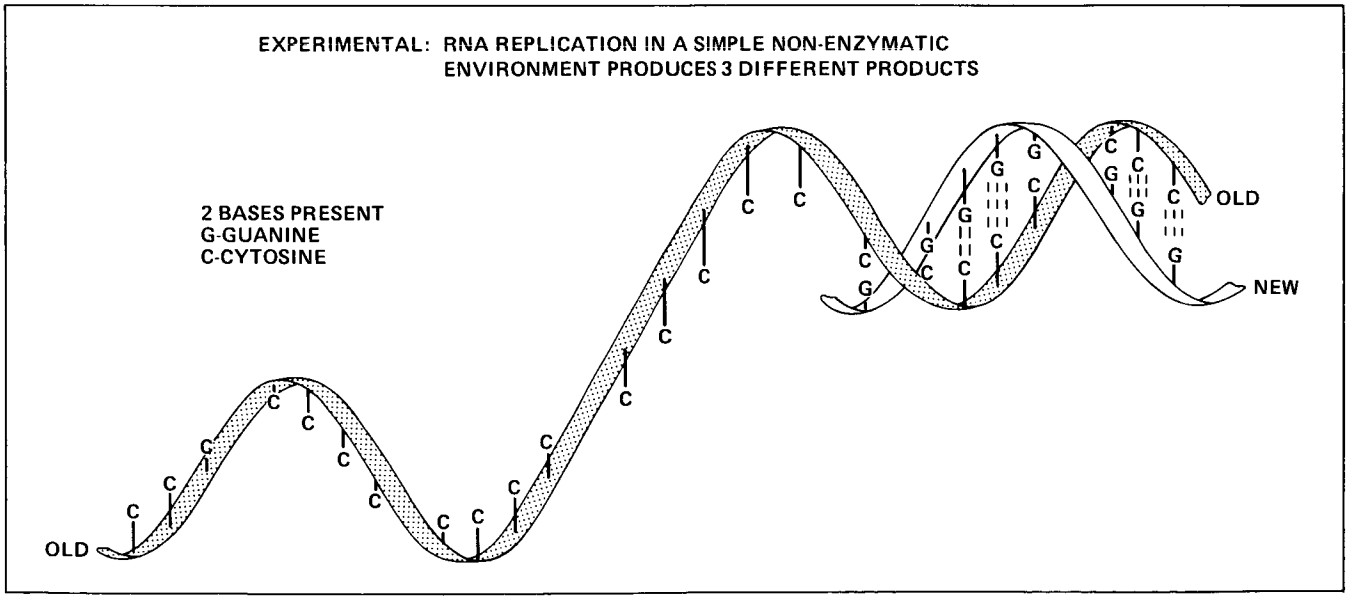
(G. Carle and R. Mancinelli, Ext. 5765/6052)

Low Temperatures Favor Selectivity in Biomimetic RNA-Synthesis

Research is being conducted to understand how the distribution of chemical compounds in the universe developed into complex, reproducing systems during the origin of life on the primitive Earth. Until recently, highly selective reactions were thought to be possible only by the action of specialized protein enzymes. However, the recent discovery of ribonucleic acid (RNA) capable of catalyzing its own self-splicing at a specific position showed that protein enzymes may not be the sole source of biological catalysis.

In biomimetic synthesis, RNA-type molecules are catalyzed by the presence of the complementary ribonucleic acid (the so-called template) in a similar way as the naturally occurring DNA transcription. In the presence of the template, a suitable experimental system resulted in the formation of short-chain RNA-type molecules (oligonucleotides). Among all the chemically possible prod-





In a simple, nonenzymatic environment, production of naturally occurring products is favored; therefore, such an environment on the early Earth was likely conducive to the replication of RNA-type molecules under lower temperatures

ucts, the naturally occurring one is favored.

This high selectivity is probably one of the most important requirements for chemical systems to serve as precursors for the first living systems. Without this selectivity, the DNA-RNA double helix would not form and the process of information transfer which underlies heredity would not be possible.

We have been studying the elongation of oligonucleotides (n units long with n = 7 to 12 units) by reaction with the activated monomer in the presence of the template. We have determined product distribution in the presence or absence of the template at two different temperatures, 37°C and 4°C. In the absence of the template, the elongation of the oligonucleotide is slow and the products are elongated no more than one additional monomer. Furthermore, three products are formed: the naturally occurring product (NP) and two byproducts (B_1 and B_2). In addition, NP is only formed in 10% yield. By contrast, at 37°C and in the presence of the template, the reaction has a much higher yield, forms longer oligonucleotides (up to n + 6 bases long) and is much more selective in favoring NP.

Interestingly, at close to freezing temperatures the full effect of the template can be realized, and only one single product is formed, the natural one (NP). This is likely due to a much tighter association between template and oligonucleotide than exists at higher temperature. The association is believed to result in the formation of one specific product. Thus, it seems that at low temperatures this chemical system mimics its biological counterpart.

It is concluded from these studies that temperatures close to freezing may have been more conducive to chemical evolution before the development of enzymatic systems. Therefore, enzymes may not have been needed at low temperatures, either in this experimental system, or in other systems where organization of matter is a prerequisite for the synthesis of highly specific biopolymers.

(S. Chang, A. Kanavarioti, and D. White, Ext. 5733/6163)

Stabilimetry in Motion Sickness Research

Evidence exists which indicates that motion sickness is much less severe (or may not occur at all) if animals or humans are not required to maintain control of their posture and equilibrium during exposure to what is normally a motion-sickness-inducing condition. This evidence indicates that motion sickness may be related to the neural mechanisms involved in the control of posture and equilibrium. Current theory suggests that these neural mechanisms monitor sensory inputs about the body's movement and orientation from the vestibular, visual, proprioceptive, and somatosensory systems and, on the basis of these sensory inputs, initiate motor commands to control posture and equilibrium. The control functions of these mechanisms are disrupted during exposure to conditions in which the normal relationships among the vestibular and other sensory inputs no longer exist (e.g., abnormal accelerations as in ships, airplanes, cars; microgravity; vision-reversing prisms; hypergravity; etc.). Under these conditions, motion sickness, as well as performance deficits and perceptual illusions, often occurs. The gradual improvement of the individual's ability to perform in these environments during chronic exposure is thought to be due to the recalibration or reprogramming of these neural mechanisms as the central nervous system (CNS) "learns" the appropriate relationships among these various sensory inputs for the new

Squirrel monkey perching on an instrumented strain-gage stabilimeter for measurement of postural sway

environment. It is thought that motion sickness (i.e., nausea, vomiting) may be a "side effect" of the changes which occur in the CNS during this adaptation or "learning" process.

To test these hypotheses about the relationship between motion sickness and postural control mechanisms, a method has been developed to evaluate changes in the ability of squirrel monkeys to control their posture and maintain equilibrium during adaptation to sickness-inducing conditions (e.g., slowly rotating room, reversed vision, hypergravity, microgravity). The degree of disruption of postural control is evaluated by measuring the postural sway of the animal as it balances on a stabilimeter (a narrow perch instrumented with strain gages for the detection of sway in the fore-aft and right-left axes). Prior to exposure to any of these environmental conditions, the animals show very little sway when the perch is stationary, and rapidly regain their balance after the perch or surrounding visual field is briefly perturbed.

The actual experiment involves determining the amplitude and frequency components of a given animal's postural sway under stationary and perturbed conditions prior to exposure to the sickness-inducing condition. Then the animals are placed in, for example, a slowly rotating environment for periods of time ranging from 1 hr to several days. The degree of adaptation of the animals to the environment is evaluated hourly by monitoring locomotion, food and water intake, and motion sickness incidents. The changes in postural control mechanisms are also evaluated hourly by placing the animals on the stabilimeter to determine the effects of the exposure on the amplitude and frequency components of postural sway under both the stationary and perturbed conditions. Changes in the parameters of sway, in motion sickness incidents, and in locomotion and food intake over the period of exposure to the sickness-inducing condition, are evaluated to determine whether a relationship exists between motion sickness and disruption of postural control mechanisms during adaptation to the abnormal environment. These results, combined with results from other neurophysiological and neurochemical studies, will contribute to an understanding of the neural mechanisms of motion sickness and of the neural and neurochemical processes underlying adaptation to motion sickness-inducing environments such as microgravity.

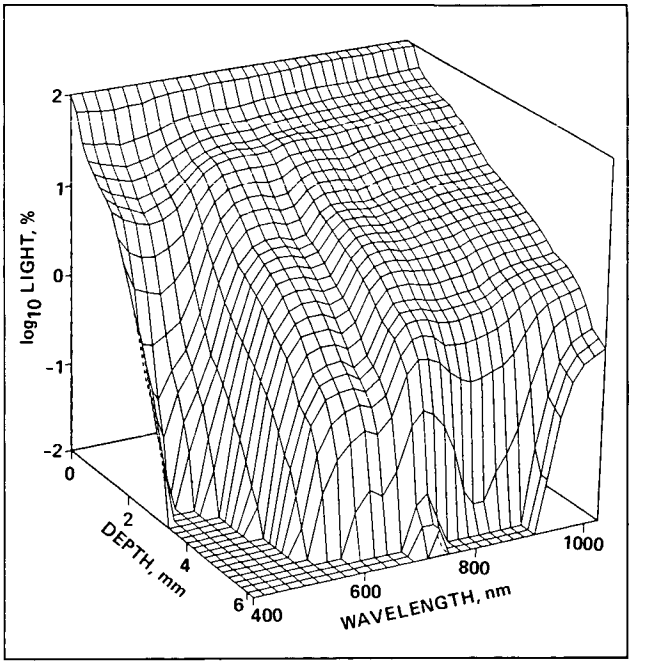
(N. Daunton and R. Fox, Ext. 6245/5574)

Measurements of Light Spectra at the Submillimeter Scale in Mats or Thin Films of Photosynthetic Microorganisms

The oldest-known fossils of life (3.5 billion years in age) are the finely laminated rocks, called stromatolites, which preserved multiple layers of microorganisms that grew on the surfaces of shallow-water sediments. Microbial mats, the living homologues of these fossils, offer us an insight into the ecology of these ancient biological communities. The living mats and their stromatolite ancestors are of interest in studies of the evolution of life on the planet as a whole.

One important aspect of these microbial communities is the utilization of various wavelengths of light by the mats' different photosynthetic bacteria. However, because the penetration of light (the "photic zone") is rarely more than a few millimeters deep in these mats, high-resolution measurements of light spectra had not been attempted within the photic zone.

Dr. Bo Jorgensen, a visiting scientist from the University of Aarhus, Denmark, has developed a



A three-dimensional plot of light wavelength and intensity versus the depth in a microbial mat. Light intensity is expressed as the percentage of each wavelength's intensity at the mat's upper surface

fiberoptic probe which can measure light spectra (at wavelengths from 300 to 1100 nm) with a depth resolution of 100 micrometers (0.1 mm) in these mats. The accompanying illustration is a three-dimensional plot which depicts how the intensities of the various wavelengths of light decrease with depth. Note that the depth ranges only from 0 to 6 mm. The uneven form of the "surface" portrayed in the figure reveals that the cyanobacteria, which are the most abundant population between 0 and 4 mm deep, and the purple bacteria, which are abundant at a depth of 6 mm, prefer to absorb and utilize different, discrete wavelengths of light.

These measurements have helped us to define the microenvironments of microorganisms as well as to determine how they compete for light and nutrients. Thus we are beginning to better understand the evolution of the Earth's earliest ecosystems.

(D. Des Marais, Ext. 6110)

The Effect of Isolation, Confinement, and Exercise Training on Human Mood and Performance During Simulated Weightlessness

With an increase in space mission duration projected by NASA, there is renewed concern regarding the effects of prolonged confinement and isolation upon the psychological well-being and performance of space mission crews. In previous long-duration spaceflights, there have been several incidences of hostility between crew members and ground-control personnel, increased tension among crew members, and increased levels of fatigue and boredom. These factors have been associated with diminished performance and sleep difficulties among crew members.

Ames Research Center is conducting exercise/bedrest studies in a Human Research Facility that simulates not only the physiological deconditioning observed during spaceflight, but the social isolation and confinement encountered during missions as well. The 1986 bedrest study provided an opportunity to assess the effects of prolonged simulated weightlessness upon human mood and a variety of performance tasks, the immediate effects of heavy aerobic exercise upon subsequent performance, and different exercise training regimens as preventive countermeasures to the expected deterioration in mood, sleep, and performance.

The performance test package consists of eight performance tasks which tap a variety of performance capabilities. This provides a broader assessment of performance capacity than that found in previous studies which used only one performance task. The performance test package consists of a series of computer programs which display each test on the screen of a portable computer.

A new mood test, based on an existing visual analog scale method, was specially developed for use in the bedrest study. This test provides a simple rapid assessment of mood which minimizes the likelihood of subject irritability and stereotypical responses observed in previous isolation and bedrest studies, higher resolution of mood state changes than was possible with standard mood questionnaires, and an assessment of mood states which is more germane to the bedrest experience, including differentiation of fatigue into physical, mental, and motivational components, and assessment of physical discomfort and sleep difficulties.

Each subject was trained on the performance test package during the orientation phase of the bedrest study and provided at least eight practice trials to eliminate learning-curve effects. The integrated mood/performance test package of 15-min duration was administered daily to each subject during the study in the late afternoon and also in the morning immediately after selected exercise regimens. Near the end of the study, the subjects were also given a questionnaire to assess their reaction to the various environmental and habitability factors encountered during bedrest. This study should provide useful information on the degree of deterioration in mood and performance which occurs in response to long-term simulated weightlessness.

(C. De Roshia, Ext. 4203)

Perfecting Exercise Regimes for Spaceflight by Use of Bedrest on Earth

Astronauts and cosmonauts have consistently exhited deconditioning (adaptation) of the body during orbital flight, requiring readaptation postflight to normal activity. Overt signs and symptoms of deconditioning persist in all space travelers for periods of several hours to several months. To study questions of major concern in the physiological systems affected by weightless-

ness, the latest in a series of bedrest simulations at Ames Research Center Human Research Facility investigated optimal exercise regimens to be used by astronauts during flight.

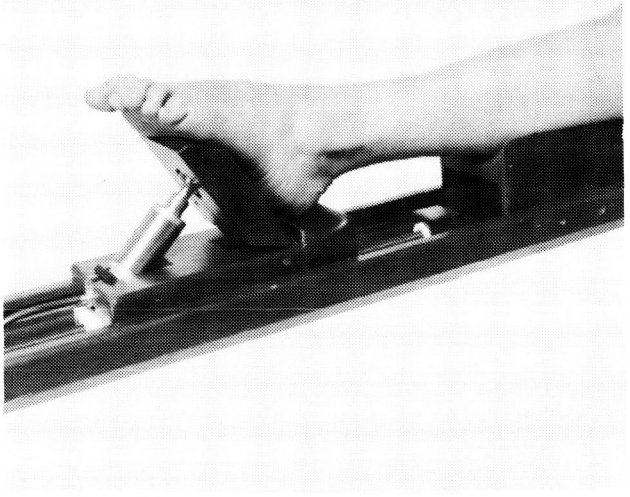
Bedrest approximates certain responses of weightlessness, and permits controlled biomedical studies and tests of possible countermeasures. The results provide a reference data base against which flight data can be compared. Remaining supine over an extended period is the key for a valid simulation. Although head-down posture does not duplicate the space environment totally, it is a very good modality for simulating the effects of microgravity on the body.

The 1986 bedrest study employed 21 healthy males (32 to 42 years old) through the Bionetics Corp., which also provided medical care and technician and administrative support for the study. Most of the research scientists were from Ames, with other researchers from the Letterman Army Institute of Research, the University of California, Loredan Biomedical, San Jose Medical Research Institute, and Toulouse Hospital, France.

The study focused mostly on leg exercise, and, to a lesser extent, on arm exercise. Spaceflight data indicate that leg strength is greatly reduced, but arm and shoulder strength seem to be well maintained. The primary objective was the comparison of cycle ergometer (isotonic) leg exercise, isokinetic leg exercise, and no exercise. A secondary objective was to determine the effect of exercise on subjects' ability to regain normal gait and movement after bedrest.

The subjects underwent various physical tests: maximal oxygen uptake, tilt-table test for orthostatic intolerance (fainting), body balance and stability, and muscle strength and range of motion tests. Cardiovascular measurements were made. Cognitive, perceptual, and motor tests were conducted; and posture, equilibrium and walking were assessed to see whether changes were due to deconditioning factors other than the changes in vestibular function which occur in spaceflight.

The different types of exercise during bedrest should minimize loss of strength and endurance. Some metabolic factors in the energy pathways in muscle were measured noninvasively using magnetic resonance spectroscopy before and after bedrest. Cross-sectional areas of leg muscle were measured weekly using magnetic resonance imaging and ultrasound. Bedrest results will be compared to results recorded from Ames' rodent experiments flown on joint U.S.-U.S.S.R. biosatellites in the late 1970s, and on Spacelab 3 in 1985. It is hypothesized that these anterior thigh (quadriceps) and calf (soleus and gastrocnemius) muscles will atrophy between 15 and 20% in nonexercised subjects, while isokinetic and isotonic exercise should reduce this atrophy to only 5 to 10%.



Device to exercise the muscle while positioning it for measurements developed for the 1986 Bedrest Study through the resources of Ames, Toulouse Hospital, and Roussel-UCLAF of Paris, France

Bedrest also provides a reasonably accurate model for studying the effects of weightlessness on bone and mineral metabolism. It appears that even more calcium is lost by the body during spaceflight than during bedrest. Ground-based simulations remain useful for the careful measurements required to determine the trigger mechanism and progression of bone-mass loss. Although bone density may be changed little after a month of bedrest, the small changes expected, when correlated with blood and urine measurements, suggest possible trigger mechanisms to be investigated more intensively. Bone turnover in the forearm and spine was measured indirectly by photon absorptiometry, without the biopsy of bone. Blood samples were also analyzed for relevant hormones and enzymes.

Considerable time and expense are required for such human studies. The study protocols and tests alone required 6 mo. But animal studies are insufficient for developing the near-term applications of exercise that must be based on human

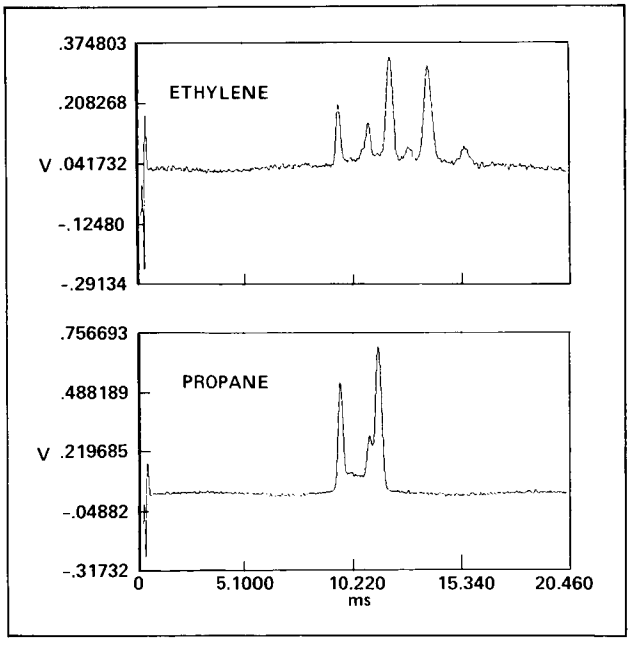
responses. Results from the study will be used in writing prescriptions for exercise on long-term Space Station flights, and in deciding which exercise devices should be placed on board.

(J. Greenleaf, S. Arnaud, and M. Cohen, Ext. 6604/6561/6441)

Ion Mobility Drift Spectrometery of Light Hydrocarbons

Ion Mobility Drift Spectrometry (IMDS) is a relatively new analytical technique now being investigated for use on future flight experiments conducting *in situ* analyses of extraterrestrial environments.

Through a process of sample ionization followed by ion separation and collection, the IMDS produces spectra that can be used to identify the sample molecules. Sample molecules are ionized to form product ions in a reactant region. An electric field moves the ions through a drift region against the flow of a drift gas, where they are separated according to their size and structure. The separated ions are then collected, producing an ion mobility spectrum which is used to identify the sample. The IMDS can be optimized for a specific chemical group by varying one or several of its operating parameters, such as electric field polarity or carrier/reactant gas, thus giving it potentially universal-identification capability. The information that can be obtained from IMDS spectra and the ease with which it can be combined with a gas chromatograph make the IMDS an ideal candidate for flight analytical instrumentation.



GC-IMDS spectra of some light hydrocarbons. GC: carrier, 20 ml/min UHP N_2; IMDS: carrier, 10 ml/min UHP N_2; drift gas, 10 ml/min UHP N_2; drift cell temp., 202°C; cell voltage, 2500 V

The commercial IMDS, however, has not been built with spaceflight in mind. As an example, the 500 ml/min drift flow rate the manufacturer recommends is totally unsuitable for flight instrumentation. In addition, many types of analyses commonly conducted on Earth with more established and easily available methods have not been done using IMDS. Thus, to fully realize its potential as a flight instrument, the IMDS must be able to conform to the rigid limits placed on such instrumentation as well as to demonstrate the capability to analyze the multitude of molecular species that future missions may encounter.

By using ultrahigh-purity gases and other methods to minimize system contamination, IMDS analysis has been conducted using drift flow rates of 50 to 10 ml/min without destroying the spectra. IMDS analysis of some light hydrocarbons using low drift flow was accomplished and similar IMDS analyses of other chemical species is under way.

(D. Kojiro, Ext. 5364)

Vector-Borne Disease

The goal of this public health program is to demonstrate the use of NASA-derived technologies in the study and modeling of environmental variables that influence the prevalence and distribution of a specific disease vector which constitutes a significant world health problem. The disease which was selected through a series of peer reviews and workshops is malaria. Malaria is an increasingly significant problem on a global basis. In 1982 the World Health Organization estimated 250 million cases worldwide. Malaria currently exists where 46% of the world's population lives, and malaria could exist where another 18% of the world's population lives. In Africa there are an estimated 71 million clinical cases annually; in the Americas there was an increase from 280,000

in 1973 to 710,000 in 1983; in middle-south Asia there are over 2.2 million cases per year; and in eastern Asia there are over 2 million cases per year. Before effective control can be attained, the disease must be defined on a large regional basis; the parts of the disease cycle that can be effectively interrupted must be identified; and this information, in a user-friendly format, must be available to health agencies on a real-time basis.

To accomplish these criteria, preliminary studies by entomologists and remote-sensing scientists of known potential disease field sites have been carried out in northern California by standard field methods and by NASA remote-sensing aircraft utilizing RC-10 (color) IR cameras, and a Daedalus Thematic Mapper Simulator (12-channel). In a collaborative effort between the University of California, Davis, and NASA, field data have been acquired on the population dynamics of the disease vector mosquito, *Anopheles freeborni,* in rice fields. These early data are indicating a spatial and temporal relationship between vector population and such environmental variables as field age, plant phenology, canopy height, water quality, and water temperature. Remote-sensing data are being used to identify potential *A. freeborni* breeding habitats (rice fields) and monitor the spatial and temporal variability of those environmental variables which can be used to predict vector population dynamics. Products in process of being developed from this research include:

1. Graphic representations of the relationships between vector population levels and environmental variables.
2. "Photo maps" of all potential breeding sites, as much as 2 mo prior to maximum vector breeding.
3. Remotely sensed characteristics and monitoring of vector habitat development.
4. Remote-sensing-based ranking of breeding sites into high/medium/low potential.

These results will be used in collaboration with the Uniformed Services University of the Health Sciences and NASA scientists to perfect a predictive model to be used for direct intervention in real-time action against the spread of malaria. Once this model is developed for northern California (Phase I), the methods will be transferred to a Phase II that will interface with the World Health Organization, the Pan American Health Organization, and American countries already fighting malarial spread.

(J. Lawless, Ext. 5900)

Multicrop Area Estimation and Mapping

Research on techniques to monitor agricultural land via the multispectral scanner (MSS) on the Landsat series of satellites continued last year under a cooperative agreement among the Ecosystem Science and Technology Branch at Ames Research Center, the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture, the California Department of Water Resources, and the University of California Remote-Sensing Research Program.

The primary goals of the project in 1986 were to complete an experiment designed to test a procedure for multicrop area estimation and mapping, and to evaluate the performance of the microprocessor/mainframe network and software configured to do the data processing. Unique features of the experiment included the amount of data processed (seven Landsat scenes, three dates per scene); the variety of crops for which acreage estimates were generated (nine major cover types or crop groups); the timeliness of the reporting (acreage estimates were ready approximately 3 mo after the last satellite acquisition); and the hardware/software combination used to generate the estimates and map products (a 16-bit, XENIX-based microprocessor developed at Ames linked to the Ames Cray-XMP and NASS PEDITOR software).

The study site for the experiment was the Central Valley of California. The first crop-specific, Landsat-based classification of the entire Central Valley was generated as part of this research.

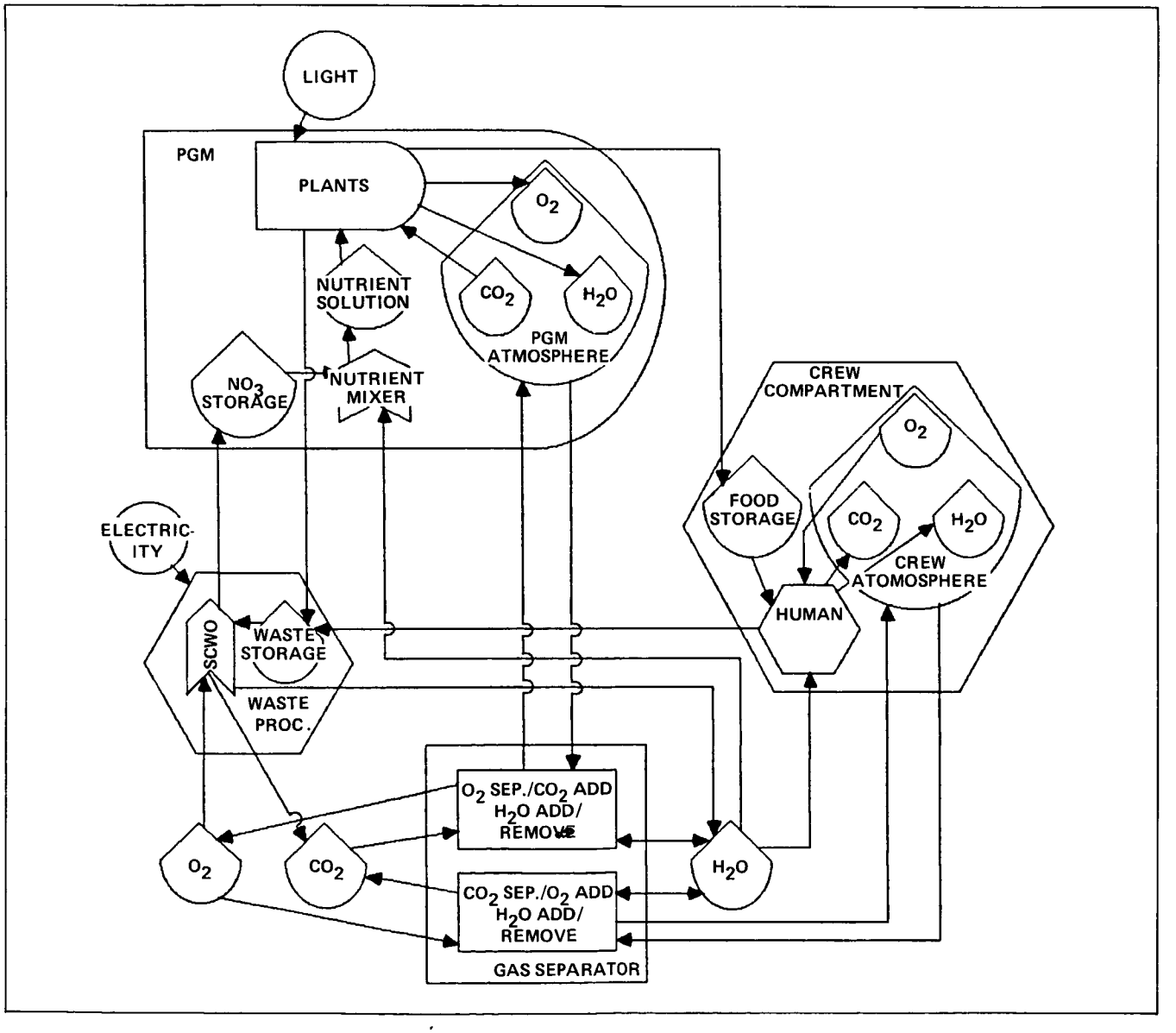
(J. Lawless and E. Sheffner, Ext. 5900/5149)

A section of the Central Valley crop classification near Bakersfield, approximate coverage — 3000 m^2, shows the use of Landsat data

Modeling a CELSS

A controlled ecological life-support system (CELSS) could potentially support human life without depending on external supplies of materials. Self-sufficient life support is regarded as an enabling technology for manned Mars exploration and the establishment of a permanent lunar surface base. A photosynthetically based CELSS will use crop plants as the main food producers and include subsystems designed to close the cycles for the four elements most important for maintaining plant and animal life: carbon, hydrogen, oxygen, and nitrogen.

One question of great interest to scientists and engineers who work with biological systems concerns the conditions for stability and control in a CELSS. For example, the coordination of material flows in Earth's biosphere is largely made possible by the presence of huge storage reservoirs that allow the buffering of material cycles. Lacking a similar buffering capacity, a CELSS will be faced with coordination problems more stringent than in any ecosystem found on Earth. A related problem in CELSS design involves providing an



A prototype modular CELSS

interface between the various processors that will provide the life-support functions of the system while still allowing for system expansion.

During the last year, a simulation model of a CELSS has been developed at Ames Research Center that will allow these and other questions to be investigated. This model is modular, in that it provides an interface for a wide variety of system processors with a set of material storage reservoirs. This allows the reservoirs to act as the principal buffers in the system, and lessens the difficulty with processor coordination. This model was used to investigate CELSS dynamics under both normal conditions and with the failure of various system components, such as the waste processor or the plants themselves. Through these simulations both system control strategies and the sizing of various system components have been studied. It has been determined that a CELSS can be made to be both stable and flexible by controlling the plants in the system and by the use of an efficient waste processor.

The modular nature of this model allows independent development of the detailed submodels that exist within the model framework, so this model can be used to investigate the behavior of increasingly complex life-support systems. Other plant species and a modified waste-processing scheme can be incorporated easily. Because the model can simulate the behavior of a complex system based on knowledge of its component parts, an evolved version of this model can be used as both a design and control aid in future CELSS development.

(R. MacElroy, J. Rummel, and T. Volk, Ext. 5573/6486)

Organic Chemistry on Titan

The Voyager flyby of Titan, Saturn's largest satellite, revealed an atmosphere composed primarily of nitrogen and methane. Voyager's discovery of nine organic molecules heavier than methane led to the deduction that the optically thick cloud layer in Titan's atmosphere is organic. This organic haze, which had long been under speculation, is being produced by methane photolysis in the atmosphere and is believed to be composed of organics with higher molecular weights than those detected by Voyager.

Titan's organic haze can be simulated in the laboratory by exposing methane and nitrogen to an electric discharge. The material produced in this manner, a dark brown, tar-like crystal, is called tholin. Tholin has been discussed as a constituent of the Earth's early atmosphere and of the organic aerosols of Titan.

It has been proposed that Titan is covered by an ocean, one to several kilometers deep, consisting of 70% ethane, 25% methane, and 5% nitrogen. This ocean could have been produced from the photolysis of methane into its primary product, ethane, which then condenses into a liquid on the surface of Titan. It is likely that the heavier organics of the cloud layer must settle down into this ocean. The question arises as to what happens to these organics once they reach the ocean: Do they eventually sink to the bottom or do they dissolve and react in the ethane? It is the purpose of this investigation to experimentally determine the nature of the soluble fraction of tholin on liquid ethane.

The experimental results so far show that a small fraction of tholin is indeed soluble in liquid ethane. This indicates that there may be organic material dissolved in the oceans of Titan. If this is the case, it would be appropriate to infer that these organics may be involved in a dynamic chemical process involving evaporation, condensation, and precipitation. A model in which organics are being recycled in this manner significantly broadens our perception of potential chemical activity on the surface of Titan and aids in the definition of future flight experiments to conduct the proper *in situ* measurements. Furthermore, because organic materials are being produced in its atmosphere, the study of Titan is relevant to the study of chemical evolution on Earth. Current experimentation involves determining the composition of this soluble fraction.

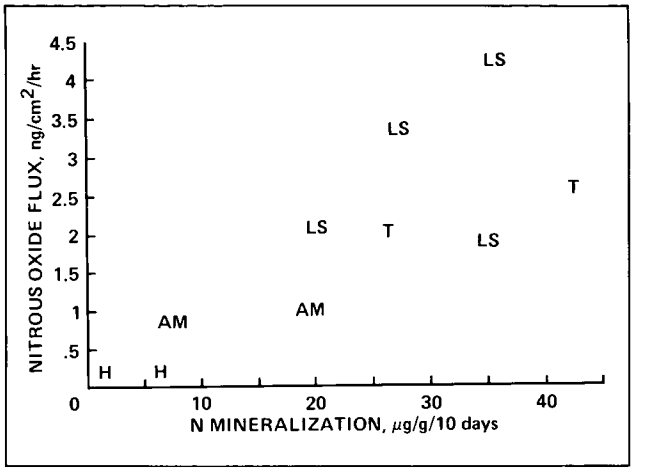
(C. McKay and J. Mathog, Ext. 6864)

Trace Gas Flux from Tropical Forest Ecosystems

Understanding the sources and sinks of important trace gases in the Earth's atmosphere is an issue closely related to predictions of climate change and the impact of anthropogenic change on global habitability. Considerable evidence suggests that tropical ecosystems, now undergoing very rapid change, are particularly important as sources of trace gases. An understanding of the role that tropical forests play in global elemental cycling, and the extent to which land clearing will affect that role, has been studied as a compo-

nent of the Biospherics Research Program.

To understand the magnitude of nitrous oxide production by tropical forests, and the processes that control trace-gas flux, forests representing a broad range of fertility and associated ecosystem processes were examined. Nitrogen mineralization, nitrate production, immobilization, and nitrous oxide production were measured in forest soils in Amazonia, lowland and mid-elevation



Nitrous oxide flux in relation to net nitrogen mineralization (release from organic to biologically available inorganic forms) in a range of tropical forest ecosystems. H represents upper montane forests in Hawaii, AM represents Amazonian forests, LS represents lowland forests on volcanic soil in Costa Rica, and T represents fertile premontane forests in Costa Rica

Costa Rica, and montane Hawaii. This research demonstrated that soils of nitrogen-rich tropical forests (those with high nitrogen mineralization — see figure) are significant sources of nitrous oxide, but soils of nitrogen-poor forests produce very little. Understanding the relationships between nitrogen-cycling processes and nitrous oxide flux allows more accurate estimation of the magnitude of flux and more accurate prediction of the potential for increases in nitrous oxide flux with change.

(P. Matson, G. Livingston, and P. Vitousek, Ext. 6884/5896)

Instrumentation and Algorithms for SETI

The Search for Extraterrestrial Intelligence (SETI) will involve a large, digital, signal-processing system, including a high-resolution spectrometer (the multichannel spectrum analyzer (MCSA) built at Stanford University), followed by a pattern detector and expert system to detect ETI signals buried in random noise, and to distinguish them from radio-frequency interference. This year much of the time of the SETI office was spent preparing a program plan for an FY 88 new initiative and giving briefings about the proposal. There was also progress in developing SETI hardware and algorithms to be executed.

A new very-large-scale integrated (VLSI) chip (a processor specifically designed for the MCSA and pattern detector) is nearing completion. Studies indicate that, using these chips and the new megabit memory chips now available, it should be possible to reduce the board count (and hence the volume) of the SETI signal-processing hardware by nearly an order of magnitude. In addition to multiple, simultaneous resolutions of 1, 2, 4, 8, and 16 Hertz needed for matching a 32-to-1 range of pulse durations, the new design provides better filtering and overlapping spectra to prevent pulses from "falling in the cracks" between two sampling intervals.

The memory requirements of the drifting pulse and carrier wave (CW) detection algorithms have been substantially reduced. The way of partitioning times to obtain near-optimum performance is now understood.

The pattern detector will probably use associative memories. Simulations show this to be particularly effective in speeding the search for sloping lines in arrays of spectra produced by drifting CW signals, and for trains of regularly spaced pulses, also possibly drifting in frequency.

Calculations show that, because of the greater bandwidth covered and the diversity of detectable signals, the proposed NASA search will be ~10 billion times as comprehensive as the sum of all previous searches.

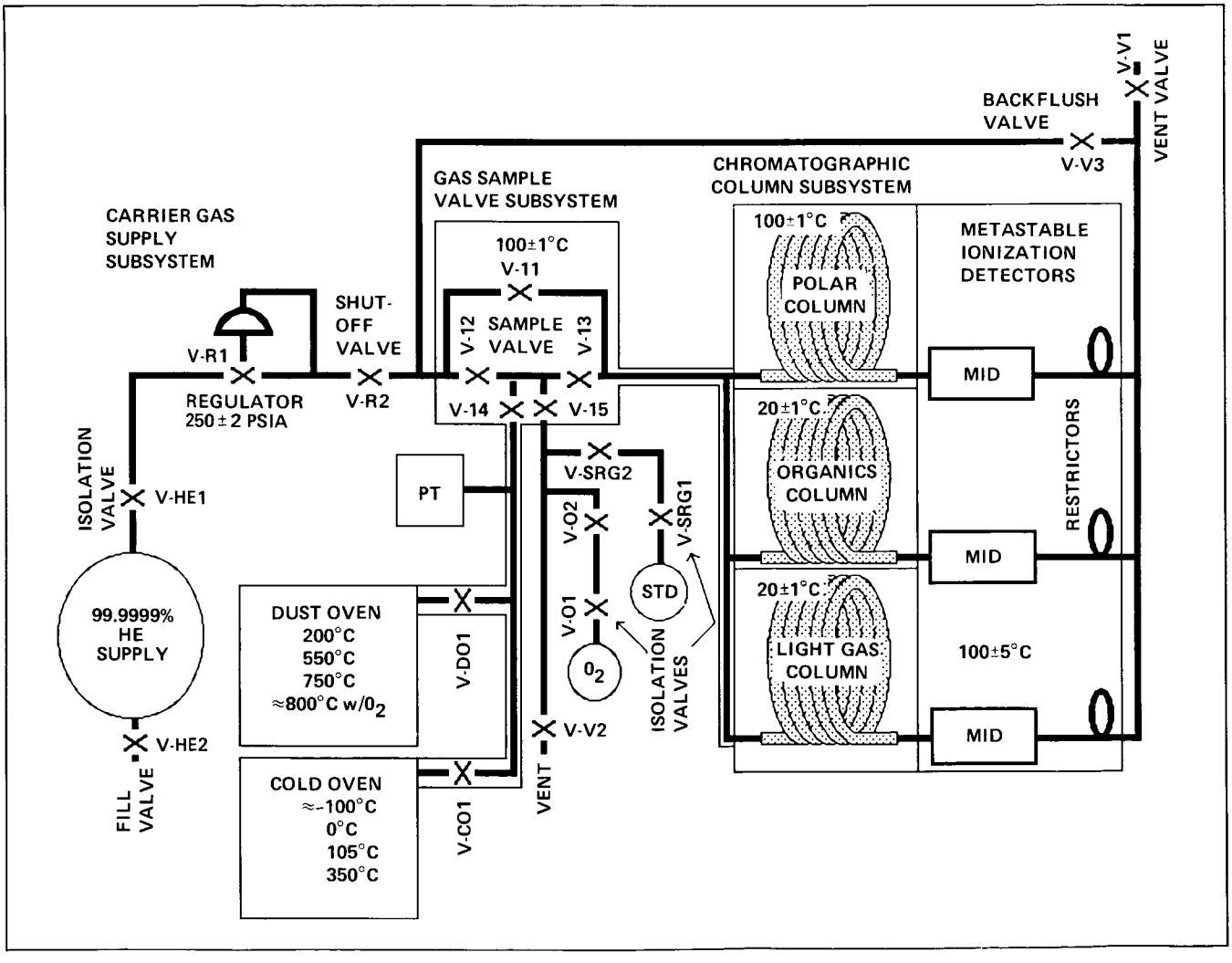
(B. Oliver, Ext. 5166)

Comet Ice and Dust Gas Chromatograph Instrument

Comets are some of the most primitive bodies in the solar system and therefore should contain chemical records of the early history of the solar system, including biogenic elements and their compounds. Determining the chemical composition of the grains and dust in the cometary nucleus would aid in placing chemical and physical bounds on the environment in which comets formed, as well as provide an inventory of elements and compounds available for planetary accretion of cometary material by the Earth. An opportunity to perform *in situ* analyses of a comet nucleus exists with the Comet Rendezvous Asteroid Flyby (CRAF) mission. A gas chromatograph (GC) instrument, proposed for inclusion aboard the CRAF spacecraft, will measure the molecular constituents of collected dust grains and ices.

The GC, using modulated voltage metastable ionization detectors and three columns designed to separate light gases, i.e., N_2, CO, CO_2; polar gases, i.e., H_2O; and hydrocarbons, i.e., $\leqslant C_4$, will measure the volatile compounds of the biogenic elements (C,H,O,N,S) thermally released from collected dust grains. The sensitivity of the GC for compounds of interest is at the picogram level. Based on work with carbonaceous meteorites, the GC can perform meaningful analyses with microgram quantities of collected comet dust, thus providing part-per-million sensitivity for the compounds of the biogenic elements.

(B. O'Hara, Ext. 5770)

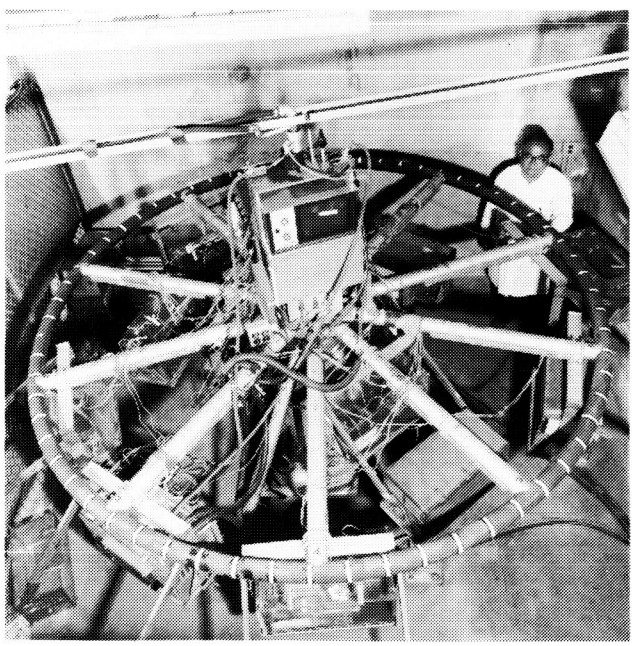


Gas chromatograph assembly

Centrifuge Research in Support of Designs for Space Station Biological Centrifuges

In preparation for using the in-flight centrifuges (1.8- and 4.0-m diam) which are now being planned for the Space Station, ground-based centrifuge studies have been initiated at Ames Research Center. This work is intended to investigate the effects of different radii and rotational rates on the growth and development of various laboratory animal species (mice, rats, guinea pigs, etc.) in different gravitational field intensities. The objective of the studies is to establish minimum radii and maximum rotational rates which will be acceptable for gravitational research on animals in space centrifuges. Small radii and high rotational rates generate other effects (i.e., g-gradients and Coriolis forces), which may confound or override the primary experimental parameter of interest: g-intensity response of the centrifuged animal.

Previous studies have determined the ability of mice, rats, and guinea pigs to mate, undergo gestation, and give birth to young at different g-intensities. In addition, postnatal growth and developmental patterns of the neonates have also been determined. The results produced by exposing animals to different g-intensities are markedly affected by the size of the animal (scaling effect of body size) as well as by the particular stage of its development. The current studies will systematically determine the effects of smaller radii and higher rotational rates on these same developmental functions.



Similar in size to centrifuges that may be used on Space Station, the 8-ft centrifuge is used to test g-gradient and rotational effects of such a centrifuge on small animals

The results from these studies are expected to provide information which will help set limits (envelopes) for the design of Space Station centrifuges, which will be used to investigate the effects of fractional-g intensities on animals in order to establish g-thresholds of changes in physiological systems. The centrifuges will also accommodate animals which will serve as in-flight 1-g controls. The information obtained will help establish the biological trade-offs between a continuous versus an intermittent mode of operation for the Space Station centrifuges, along with design and operational requirements for animal housing, life support, experimentation, and monitoring systems.

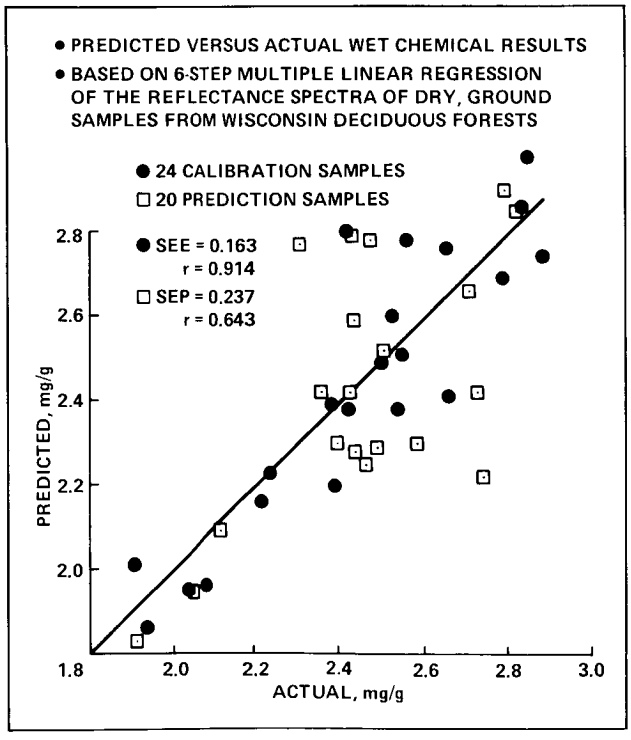
(J. Oyama, Ext. 6246)

Near-Infrared Reflectance Spectroscopy of the Nutrient Status of Forest Canopies and Leaves Using Remote Sensing

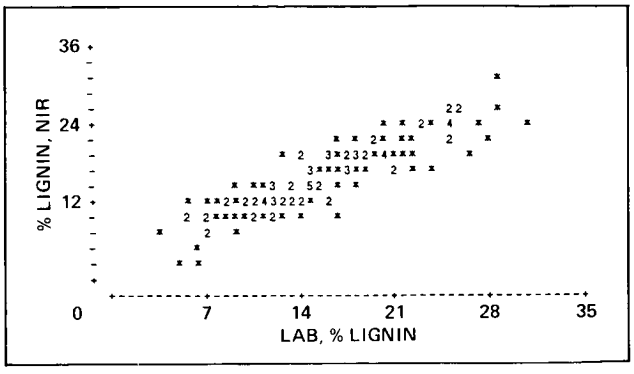
Ames Research Center scientists, working with university scientists, have been investigating the potential to use near-infrared reflectance spectra for estimating the biochemical content of plant canopies and leaves. Organic compounds such as proteins, cellulose, lignin, and starch selectively absorb shortwave infrared radiation. These absorption properties are heavily overlapped in the shortwave region, where water also absorbs strongly. By analyzing spectral reflectance data acquired both in the laboratory and from airborne spectroscopic sensing systems, and then comparing these spectra to organic chemical analyses conducted in a wet chemical laboratory at Ames, the science team is beginning to develop predictive relationships. By providing needed information on large contiguous regions, this new technology will make a significant contribution to the study of how forest ecosystems control and use nutrients. The data will be incorporated into simulation models of forest ecosystem dynamics to predict their productivity and nutrient turnover. The information required for simulations consists of the nitrogen and lignin

content of forest canopies, together with their climatological conditions.

From four different sites throughout North America (Alaska, Oregon, Wisconsin, and California), scientists have collected fresh leaves from the canopies. Several hundred samples have been gathered and analyzed in the wet laboratory and measured in spectrophotometers. Stepwise regression analyses have demonstrated that the nitrogen and lignin content of the dried, ground samples can be predicted from their spectral reflectance properties. A set of calibration samples is used to develop calibration equations between spectral reflectance and actual wet chemical content. Calibration samples are also used to predict the biochemical content of a set of unknown samples. The relationship studied between actual and predicted nitrogen and lignin content of leaves from a variety of tree species can be seen in the figure. Nitrogen was predicted with a coefficient of correlation of 98%, and lignin with 78%. The standard errors of prediction are comparable to the errors encountered by the wet chemical techniques. Similar results (not shown) are beginning to be developed from spectral reflectance analysis of fresh, whole leaves of conifer species, in which the nitrogen content has been predicted with a standard error of prediction of 15.8%. The wavelengths selected for these predictive relations generally correspond to known spectral absorption features of the appropriate organic molecules. These results provide strong evidence that reflectance in the shortwave infrared spectral region is influenced by absorption by biochemical compounds within leaves.

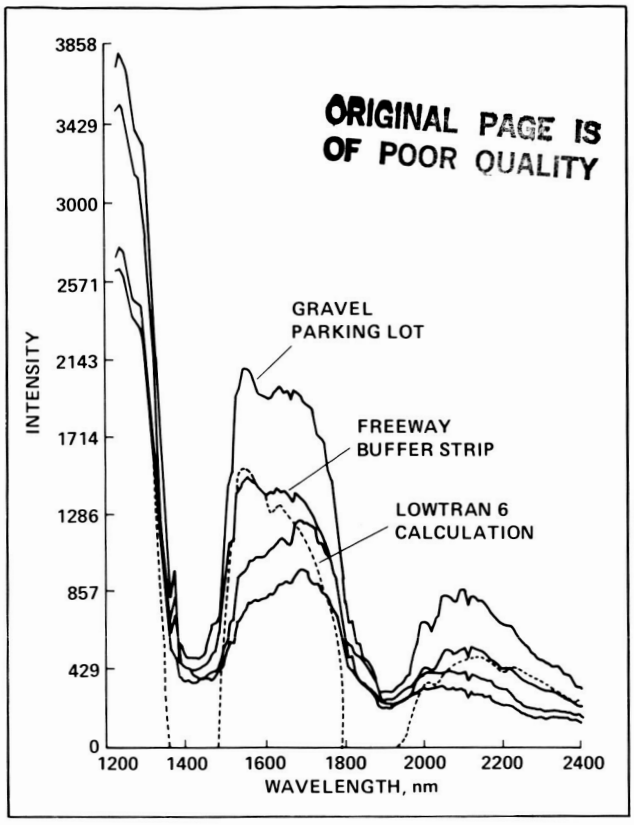


Prediction of leaf nitrogen concentration from spectral data



Spectra from AIS for two forest canopies (Gal., SW) of mixed deciduous compared to spectrally flat targets (measured and calculated by LOWTRANG 6)

This investigation is ultimately concerned with whether similar information can be reliably developed from airborne sensors for whole forest canopies. Spectroscopic images of forest canopies can be obtained with a new NASA instrument that is still in the experimental stages. This instrument, the airborne imaging spectrometer (AIS), was developed by NASA's Jet Propulsion Laboratory. The AIS produces images with 128 spectral bands, each band 10 nm wide. The AIS was carried over the forest research sites aboard Ames' C-130 aircraft. In the 1985 R&T report, we showed that a strong inverse correlation was found between the total foliar wet biomass of deciduous canopies and the signal from the AIS for our Wisconsin sites. Further evidence of biochemical absorption is obtained by comparing biological spectra with spectrally flat fields. In the second figure several forested site spectra are compared with the response from a freeway and a gravel parking lot; overlaid on this figure is a calculated response from a flat field given the solar and atmospheric conditions present when the imagery was obtained. This calculation was made from an Air Force program called LOWTRAN. The similarity of the freeway and LOWTRAN indicate that the freeway is probably spectrally



Results of prediction of lignin concentration of dried, ground deciduous leaves using derivatives of spectral reflectance from laboratory spectrophometer

flat so that the envelope between the freeway and the forest spectrum is a biological absorption characteristic. Each of the laboratory studies, and those of other researchers, indicates that this region corresponds to absorption by lignin and possibly starch. Our whole canopy biochemical contents of lignin and starch are also correlated with this feature. This initial result is promising and is being verified by other studies.

(D. Peterson, M. Spanner, N. Swanberg, and P. Matson, Ext. 5899/5896/6884)

Reduction of Spermatogonia and Testosterone in Testes of Rats Flown on Spacelab-3

Rats flown on Spacelab 3 (SL-3) provided an opportunity to measure the effect of spaceflight on spermatogonial cell population and testosterone level.

CONTROL

FLIGHT

Darkly stained spermatogonial cells are "stacked" along the periphery of the testicle tubule in a control sample. Such "stacked" cells are not present along a similar boundary from a flight sample

The testes from six of the rats flown on SL-3 provided material for weight determination and spermatogonial cell-loss quantification. Another seven animals, maintained on the ground at Kennedy Space Center (KSC) in identical cages, provided the control tissue. The Shuttle flight lasted 7 days and landed at Edwards Air Base, CA. The animals were then flown to KSC in a Lear jet (6-hr flight). Plasma was available to measure the testosterone levels in an additional seven flight and seven control animals which had an average weight of 400 gm.

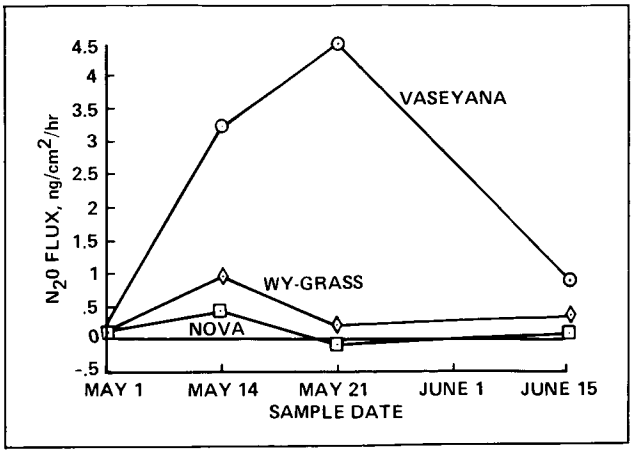
The average weight loss of the Shuttle-flown rat testes was 7.1% as compared to the controls. Counts of the stage-six spermatogonial cells showed a 7.5% decrease in cell population, t-Test significant to 0.01. The testosterone level of the large control rats compared to the large flight rats was a 30:1 ratio. The testosterone ratio in the smaller control vs. flight rats was 10:1. The volume of interstitial tissue appeared reduced. There was also a reduction in the amount of lipid droplets in the tubules of flight animals.

The testis is known to be very sensitive to many environmental factors including radiation and stress. Dosimetry from previous Shuttle flights indicated a dose factor of approximately 0.05 r in the designated animal area. Since it would take about one rad of cosmic rays to reduce the measured cell population by the observed amount, radiation cannot be considered as the primary cause of the observed change. Stress from adapting to weightlessness, the final jet flight and/or other factors must be considered. Since the cages, both on the ground and in space, contained the same number of animals and were identical, the effect of animal crowding would not be considered a variable. It is clear that spermatogenesis and testosterone production were significantly reduced during the SL-3 experiment. The site of action of these changes and the mechanisms by which they interfere with both spermatogenesis and steroidogenesis need further investigation.

(D. Philpott and J. Stevenson, Ext. 5218/5061)

Biogeochemical Cycling in Sagebrush Ecosystems

Sagebrush ecosystems cover large areas of the United States, and are representative of steppe ecosystems around the world. Because of the undulating terrain and harsh climatic conditions



Nitrous oxide flux from three sagebrush communities. "Vaseyana" refers to Artemesia tridentata subsp. vaseyana *communities; "Wy-grass,"* A. tridentata subsp. wyomenenis-*grass communities; "Nova,"* A. nova-*cushion plant communities. Preliminary data*

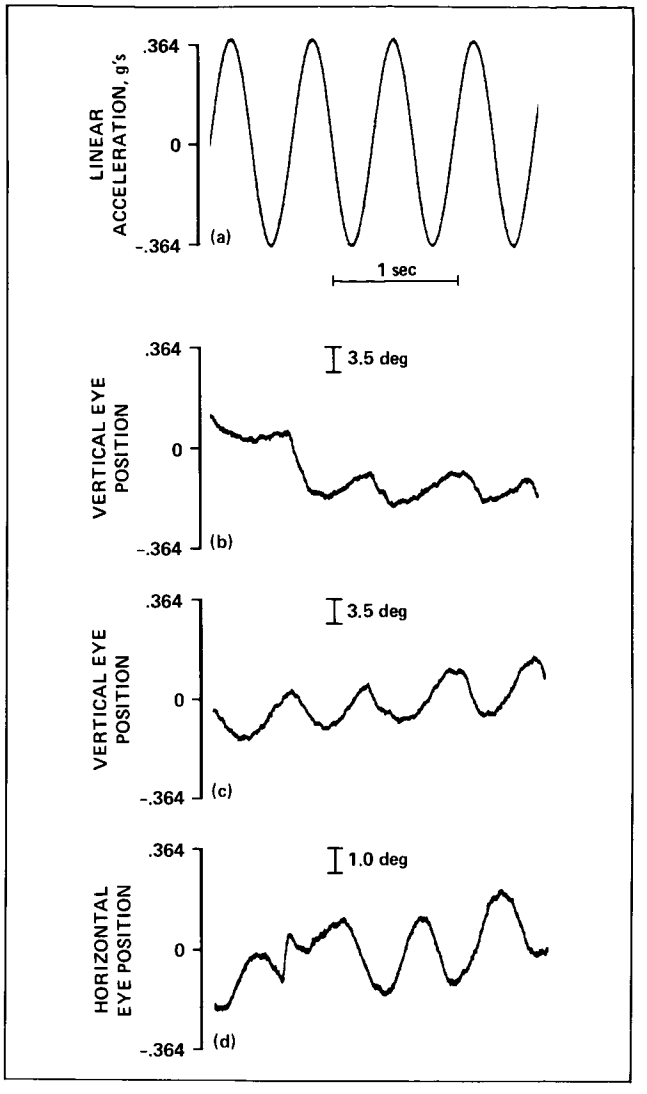
in these areas, vegetation patterns are dictated in large part by landscape position, and biogeochemical processes must be evaluated in terms of this underlying pattern. This close relationship of process to landscape pattern makes sagebrush ecosystems good test sites for the use of remote sensing in predicting ecosystem processes.

Landsat Thematic Mapper (TM) data are being used to predict ecosystem processes (including nitrogen cycling, phosphorus availability, and nitrous oxide production) as they relate to vegetation and soil reflectance characteristics. Both ground-based research and remote-sensing research have indicated that seasonal variation in sagebrush ecosystem processes is extreme (see figure). Thus, remote-sensing data scanning, both temporal and spatial scales, is necessary for accurate predictions of sagebrush ecosystem processes.

(L. Strong and P. Matson, Ext. 6184/6884, and W. Reiners and I. Burke, 307-766-2235)

Gravity Receptor Physiology in the VRF

During dynamic pitch, roll, or yaw head movements, sensors within the vestibular system provide signals of head position and angular velocity in inertial space. The sensors are the biological equivalent of linear and angular accelerometers,



Accurate measurement of the small eye movements elicited by gravity-receptor stimulation in an alert animal

and the signals they emit are used by the brain to produce eye movements which compensate for the head movements. Thus the vestibular system helps to keep the eyes — and therefore the visual world — stable in inertial space. The exact mechanisms by which these controls take place are not totally understood, especially the way the head's position and rate sensors interact in the brain.

It is particularly important to understand the role of vestibular sensors signaling head position relative to Earth's gravity. Past work has suggested that these sensors play a critical role in the control of vertical eye movements (those reflexively produced by pitching or rolling the head), but it has never been unambiguously shown that linear accelerations can produce vertical eye movements. Past work suggests that these eye movements will be small relative to those elicited by rotational stimuli.

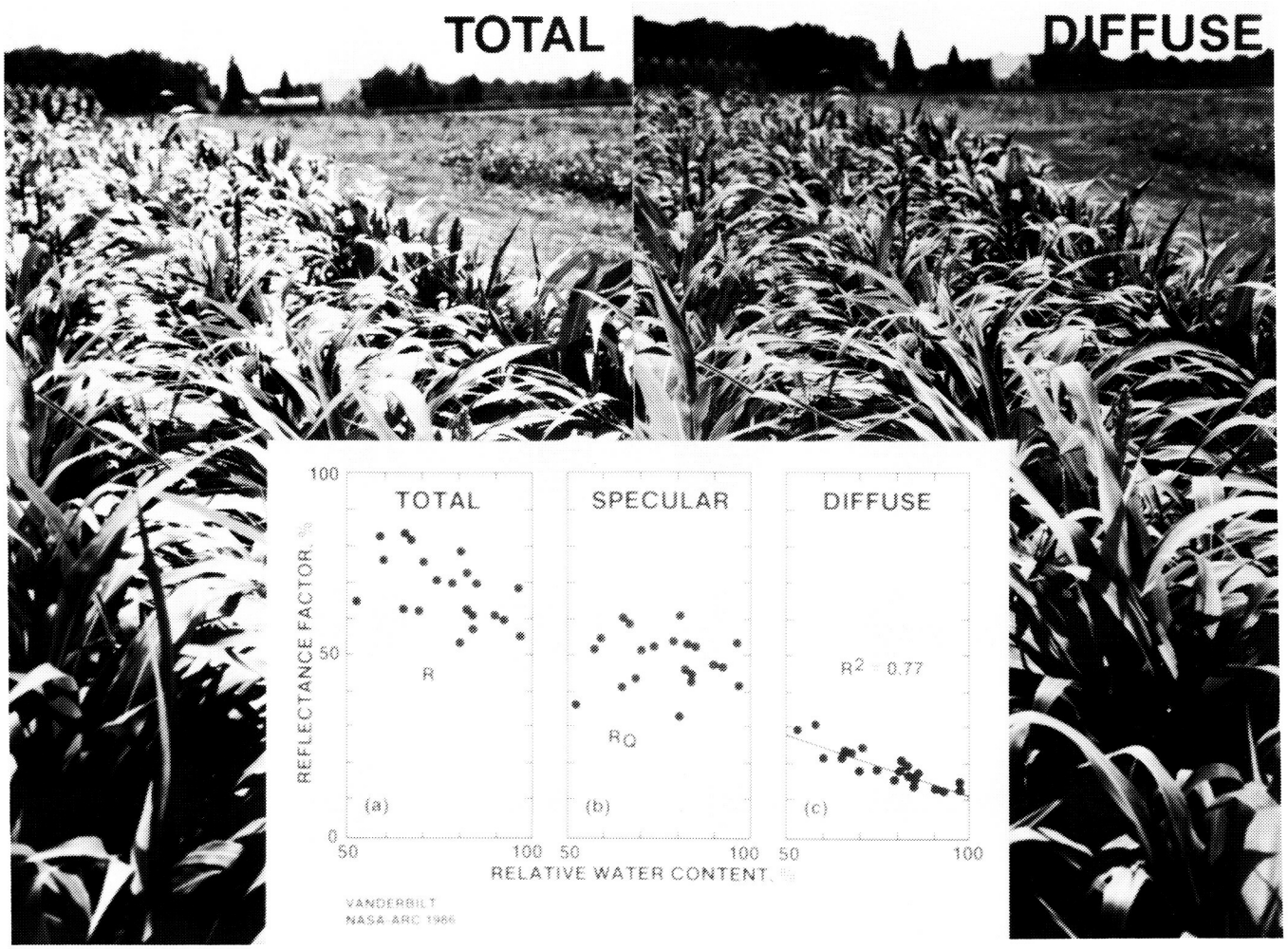
To address the question of whether pure linear accelerations (gravity-receptor stimulation) can elicit rotational eye movements, experiments were conducted on the low-vibration Vestibular Research Facility (VRF) linear sled using squirrel monkeys. Samples of data are shown in the figure: accelerometer measure of sled oscillations (1.5-Hz, 0.36-g); oscillatory vertical eye movements generated by chest-spine and head-tail accelerations; and horizontal eye movements elicited by left-right linear acceleration. Measurement of these eye movements under these linear acceleration conditions was possible only with the vibration-free VRF sled and a technologically advanced means of measuring eye movements. These results have important implications for human operations in microgravity since they directly indicate that gravity receptors play a role in the reflexive control of eye position, and thus in the stabilization of visual space.

(D. Tomko, Ext. 5723)

Measuring Water Stress in Plants: Polarization of Light Scattered by Vegetation

Preliminary research results suggest that with the aid of satellite-borne sensors the water status of vegetation eventually might be monitored over large areas of the Earth — continents possibly. While much research remains to be done, these preliminary results open up the possibility that the effects of rainfall — and particularly drought — on global vegetation and climate might be better gaged and their impact modeled.

The figure shows there is a linear relationship between the relative water content of a corn leaf, measured *in situ,* and the amount of nonpolarized light which is scattered by the interior of that leaf. Estimating this scattered light depends upon a new analysis technique, involving the measurement of polarized light. The reflectance of the leaf is divided into two fractions — one reflected from the leaf surface and polarized, and the other fraction reflected from the leaf interior, which contains the photosynthetic machinery. The figure shows that there is no relationship between the relative water content and the surface



When the bidirectional reflectance factor (R) of 21 moisture-stressed corn leaves measured in situ in the red spectral region was divided into two fractions, a linear relationship was found between the nonpolarized, diffuse light scattered by the leaf interior and its moisture status. No such relationship was found for the other fraction — the surface-reflected, polarized, specular glare (R_Q)

reflected light (the glare), which is polarized by specular reflection.

Future research will seek to determine how these results for individual leaves may be extended to plant canopies, which may change their reflectance because of architecture changes when moisture stressed, and to species without pronounced leaf-surface glare.

(V. Vanderbilt, Ext. 6184)

Highly Compact Chromatographic Trace-Gas Analyzers

Several prototypes of highly sensitive, compact, gas chromatographs for trace-gas analysis are in continuous use at Ames Research Center. Substantial reductions in mass and volume make this kind of instrument an even better candidate for future use in manned and unmanned space exploration than earlier successful chromatographs.

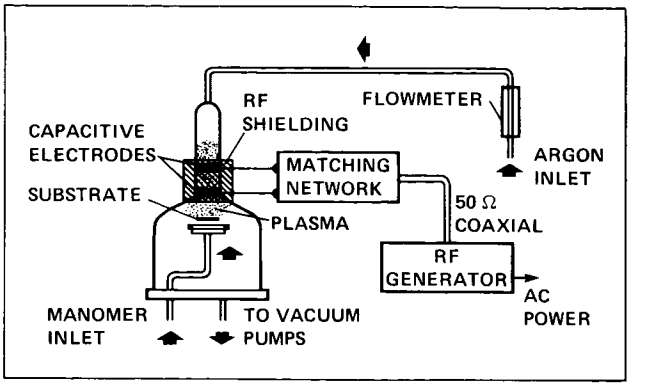
The compaction of the instruments was possible after a thorough demonstration that the ultrasensitive helium ionization detector can reliably run at flow-rates of as low as 1.5 cm^3/min. This implies a reduction of carrier gas reservoirs by a factor of about 20 when compared to previously customary dimensions. Concurrent with this was the successful design of miniature detectors, and of separation columns of smaller dimensions.

The miniaturized gas chromatographs are largely nondiscriminating, and measurements in the concentration range of 2 to 50 parts per billion of trace-gas constituents in planetary or vehicle environments have become a reality.

(F. Woeller, Ext. 5769)

Sunglass Lenses—Made to Last

A chemical process resulting from space research was used to significantly improve sunglass-lens technology. A greater degree of lens hardness, and consequently, greater scratch resistance, is achieved by depositing a thin plastic coating on a dissimilar plastic sheet. Under normal wear conditions, the new scratch-resistant lenses last 10 times longer than the most widely used plastic optical lenses. This new technology was developed as a result of research conducted to improve a spacecraft water purification process. In order to improve the thin, semipermeable membranes used in the purification process, a porous filter was coated with a thin plastic, semipermeable film using the electric discharge of an organic vapor. Later, an abrasion-resistant coating and process for polycarbonate visors was developed for NASA space helmet visors. Increased surface hardness, or scratch resistance, results from a process in which organosilane compounds are plasma-polymerized and then treated for a short time with an oxygen glow discharge. A typical plasma polymerization system is shown in the figure.



A typical plasma-polymerization system was used in developing a chemical process to make improved membranes for spacecraft water purification. This process was also used to manufacture scratch-resistant eyeglasses

Although ground and polished tempered glass traditionally has been the preferred lens in the eyeglass industry, polarized and other plastic lenses have made important inroads in recent years because of their lower manufacturing costs, excellent optics, and better absorption of dangerous ultraviolet radiation. Additionally, they are lightweight, resistant to shattering, and easy to shape. Susceptibility to scratching and subsequent reduction of visibility have been the major limitations of plastic lenses. The coating process made available through NASA licensing substantially corrects these tendencies.

Foster Grant, one of the world's largest manufacturers of nonprescription sunglasses, obtained a license from NASA to use the process in 1983. The new process, known as plasma- or glow-discharge polymerization, holds the NASA record for the most units made and sold under a NASA license (more than 5 million pairs since 1983), and is second highest in royalties to NASA.

(T. Wydeven, Ext. 5738)

Infrared Image Reconstruction

Present infrared array devices have imaging characteristics which fall well short of ideal. In particular, pixel-to-pixel crosstalk within an array can be significant. For example, an imaging infrared camera system developed at Ames Research Center uses an Aerojet 16- by 16-element Si:Bi IR array. This array has been shown to have 20% crosstalk in the horizontal dimension and $<1\%$

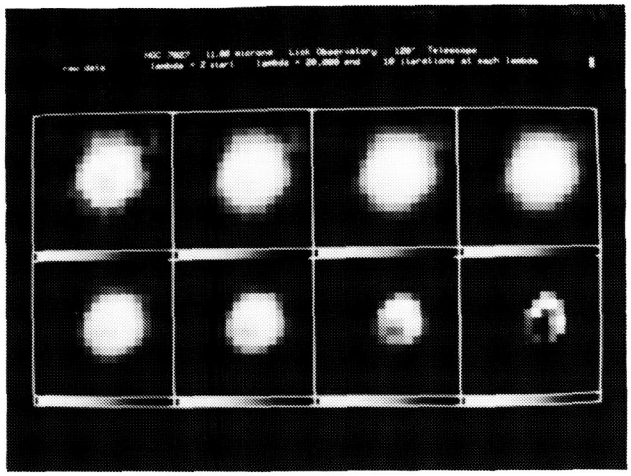


Image of NGC 7027 (11.80 μm) reconstructed with MEM

crosstalk in the vertical dimension because of electronic coupling between the output transistors.

Ames scientists have adapted the maximum entropy method (MEM) of image reconstruction to demonstrate that these array-induced smearing effects can be removed from astronomical images. By operating with a measured (rather than a modeled) point-source spreading function, the method permits the digital reconstruction of the basic unsmeared image. The MEM has been shown to be effective irrespective of the source (i.e., atmospheric or electronic) of the smearing function.

The accompanying figure shows an image of the planetary nebula NGC 7027 taken at 11.80 μm with the Ames infrared camera. The figure shows the MEM reconstruction process step by step, starting with raw data (upper left), through the terminating iteration (lower right). The MEM-produced final image shows a ring-like structure with a nonuniform intensity distribution, consistent with previously observed structure in this object.

(J. Goebel, Ext. 6525)

Development of Low-Background Test System for Large Integrated Infrared Arrays

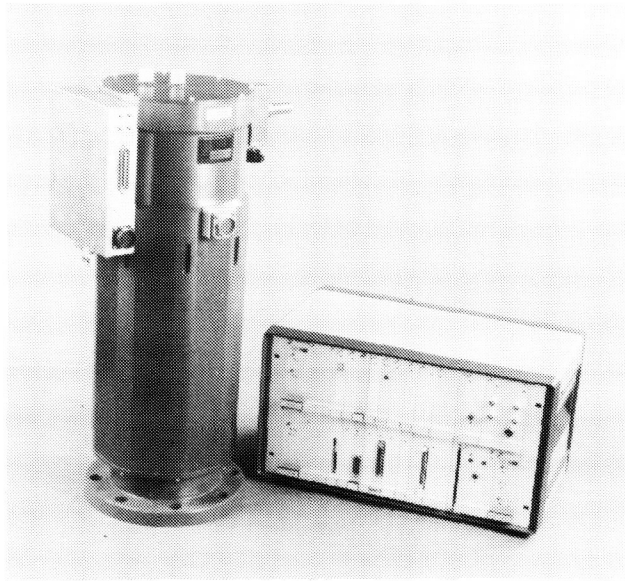
During FY 86, a test station which includes a specially designed liquid helium dewar and a microcomputer-based electronics and data system was developed and demonstrated. With this system, large integrated arrays of infrared detectors can be characterized under the low-background environments anticipated for future orbiting cryogenic astronomical telescopes such as the Space Infrared Telescope Facility (SIRTF).

The test dewar was designed to achieve exceedingly low infrared flux levels, ultimately down to $\leqslant$10 photons/s-pixel, on an array. To achieve these levels, low-temperature internal baffles and multiple filters are used. Miniature coaxial cabling was installed throughout, and modules with internal blackbody sources and a rotatable filter wheel can be readily added.

The necessary timing patterns and dc voltages for a particular infrared array are provided by a flexible 68000-based electronics system, coupled to a Sun 2/120 workstation via Ethernet. Output signals can be sampled in a variety of ways. Operating parameters (e.g., the clocking patterns and frame rates) are controlled and configurable by the Sun. A color monitor produces full-field displays of signal or noise distributions, and data are processed and displayed in functional and statistical formats.

This system will now be used to characterize a 58- by 62-element Si:Sb infrared array produced by Santa Barbara Research Center. This technology has been adopted as the baseline for the 18- to 30-μm band of the SIRTF Infrared Array Camera.

(M. McKelvey and G. Anderson, Ext. 6525/6548)



Dewar and drive electronics chassis for low-background large infrared array test system

Thermal Acoustic Oscillation Predictor

Thermal acoustic oscillations (TAO) occur spontaneously in the fill and vent systems of cryogenic vessels. TAOs are the movement of gas back and forth along a cryogenic plumbing line, driven by its temperature gradient. They result in large unwanted thermal loads on the stored cryogens. While this phenomenon has been known for a long time, there has been no adequate tool for predicting its occurrence. Without a design tool available, the dewar designer has been faced with one of two choices: design anti-TAO devices into all fill and vent lines, or retrofit anti-TAO devices after the dewars have been fabricated and tested.

Researchers at Ames Research Center have developed (in conjunction with the National Bureau of Standards) a design tool that allows the stability of a fill or vent line to be determined analytically for an arbitrary temperature distribution. This allows the dewar designer to determine the stability of the lines early in the design process. Then, if a line is predicted to be unstable (or nearly unstable), it can be redesigned or an anti-TAO device can be included.

This predictor can be used in the design of any stored cryogenic system. It is of most use in the design of stored liquid hydrogen, solid hydrogen, liquid helium, and supercritical helium systems, since these are most susceptible to TAOs. Programs such as SIRTF, GP-B, LDR, and Space Station will directly benefit from its use.

(P. Kittel, Ext. 6525)

Method to Cancel Stellar Scintillation

The turbulence in our atmosphere causes stellar images to appear to flicker in intensity. This scintillation limits the precision of short-period photometric measurements made through the atmosphere. The study of rings around planets and the turbulence in other planetary atmospheres would benefit if scintillation could be cancelled or at least reduced. At periods greater than a few minutes, photometric precision is limited by variations in atmospheric turbidity. If both scintillation and turbidity variations can be cancelled, a wide range of astrophysical observations can be improved. An instrument (a two-color filter) is being developed to test concepts to reduce scintillation and correct for turbidity variations by the simultaneous observations of two or more stars in two colors. Calculations indicate that the ratio of ratios (i.e., the ratio of the color one of star one to color two of star one to the ratio of color one in star two to color two of star two) should increase the measurement precision by nearly a factor of 10 at small zenith angles.

(W. Borucki, Ext. 6492)

Development of a Planetary Detection Photometer

When a planet passes in front of a star, the light flux from the star is reduced. The magnitude of the reduction is proportional to the ratio of the area of the planet to the area of the star. A transit of the Sun by Jupiter or Saturn would cause a 1% decrease in the flux, while a transit by the Earth or Venus would cause a 0.01% decrease. However, the precision of current high-quality photometers and spectrophotometers seldom reaches 0.1%. The key to increasing the precision of photometric systems is in the development of ultrastable, ultraprecise detectors that need no calibration. NASA Ames Research Center and the National Bureau of Standards are developing a spectrophotometer based on ultrastable silicon diodes. The joint effort is aimed at developing a many-channel spectrophotometer that has a precision of 1 part in 100,000. Because the orbital planes of planets orbiting other stars are expected to be randomly distributed, it is unlikely that a star will show planetary transits even if the star has planets. To obtain a detection rate of several solar systems per year of observation will require a photometer that can monitor hundreds of stars simultaneously. Thus it will be necessary to use optical fibers to couple the output of a wide-field telescope to an array of detectors. Although the photometer is being designed for use on the Space Station, this instrumentation can be expected to have many industrial, medical, and scientific applications. Such applications include image-processing and enhancement, detection of trace amounts of chemicals and pollutants, and in remote sensing systems.

(W. Borucki and L. Allen, Ext. 6492/6524)

Laser Simulation of Planetary Lightning

Spacecraft observations have shown that lightning is a common feature of planetary atmospheres. Measurements of lightning activity in these atmospheres is expected to give insight into meteorological processes, and to help elucidate the evolutionary processes that have produced the present atmospheric compositions. In particular, lightning produces significant amounts of trace gases and prebiological molecules. To interpret spacecraft observation measurements, it is necessary to simulate lightning in the laboratory. Until recently, it has been necessary to use large electrical arcs to do so. These arcs are often contaminated by material vaporized from the electrodes and are hazardous when used in flammable gases such as those present in the atmospheres of the major planets and Titan. At Ames Research Center we have found a new way of simulating lightning that overcomes these difficulties. We focus light from a pulsed laser into a small flask containing the mixture to be flashed. The electric field at the focus causes the gas to break down and form a high-temperature plasma. Because there are no electrodes and because the laser radiation is not absorbed by the flask nor by the atmospheric gases, neither the plasma nor the radiation from the plasma is contaminated. Consequently, spectrometric and gas chromatographic studies can be carried out with very small volumes of gas. Preliminary characterization of the laser-induced plasmas indicates that they accurately simulate lightning discharges.

(W. Borucki and C. McKay, Ext. 6492/6864)

Origin and Evolution of Planetary Systems

A broad-based, multidisciplinary effort is under way at Ames Research Center, which focuses directly on problems, processes, and events which trace the formation of the Earth and the other planets from the dusty interstellar gas.

Studies of the solid material in thick galactic clouds are best conducted at infrared wavelengths which can penetrate to the warm centers of these clouds, where the formation process is most active. Ames astronomers utilize the Kuiper Airborne Observatory and their own advanced detector technology to probe the structure of these regions and study the compositional makeup of the silicate-organic grains found there. Ongoing laboratory studies attempt to simulate interstellar grain properties. Theoretical dynamical studies of the collapse and early evolution of a gas and dust cloud are being conducted which allow us to predict the thermal properties of the planetary formation environment.

Subsequent stages in the history of solid material are poorly understood; as macroscopic objects grow and interact, their behavior may be similar to that seen in planetary rings, which are being studied in depth observationally and theoretically with the aid of an advanced image analysis system. Certain primitive meteorites contain many clues to the growth of solid objects, and are being studied using electron microscopy and other techniques. Comets also represent primitive bodies in their original form, and several groups of Ames scientists hope to explore a comet nucleus at close range as part of the proposed Comet Rendezvous mission. A combination of events led subsequently to the accumulation of planets from mountain-sized planetesimals; the formation of gas giants such as Jupiter and Saturn, for instance, might have begun with a slow accumulation of solids, but apparently ended with a rapid collapse of the surrounding gas onto the solid core. This process, and the subsequent chemical and physical evolution into planets as seen today, are also under study theoretically. The variety of possible end states for solar system formation is a question which may be constrained observationally, and Ames researchers are playing central roles in planning future observational studies of planetary constituents of other stellar systems using space-based astrometric, spectroscopic, and photometric techniques.

In many of the above areas, extensive collaboration exists between Ames researchers and scientists at Berkeley, Santa Cruz, and Stanford.

(L. Caroff, P. Cassen, and S. Chang,
Ext. 5523/5597/5733)

Formulation of Stars and Planets out of the Interstellar Medium

Theoretical work on the interstellar medium supports Ames Research Center's program in infrared astronomy. The dust and gas in the interstellar medium emits most of its energy in the infrared, and theoretical models provide the link between the data and physical properties of these

emission regions. Observations of interstellar gas and dust, especially in star-forming regions, form the bulk of the infrared data gathered from the Kuiper Airborne Observatory (KAO), the Infrared Astronomical Satellite (IRAS), and other infrared observatories.

The major accomplishments of the Center for Star Formation Studies in FY 86 are reflected in results on the various stages of the star-formation process, including the gravitational collapse of interstellar gas and dust to form a protostar, the evolution of the orbiting gaseous disk around the protostar, the evolution of the protostar, and the interaction of the newly formed star with the surrounding interstellar medium.

We have shown that low-mass stars may form out of interstellar gas which is supported against gravitational collapse by the pressure of magnetic fields, whereas high-mass stars form from interstellar clouds of gas where magnetic fields are relatively weak. The collapse of low-mass stars like the Sun has been studied in detail. The theoretical models indicate the formation of a central protostar and an orbiting nebular disk. The protostar grows by accretion of material directly falling on it from the interstellar cloud as well as by accretion of spiraling material from the disk. We have modeled the infrared emission from the protostar and disk and have shown that the disk makes an important contribution to the midinfrared emission, an effect which is observed in nearby regions of star formation. The protostar grows to a mass equal to that of the Sun in about 10^5 to 10^6 yr, and we have speculated that it then produces a wind which terminates further accretion. The disk evolves on a similar timescale to form protoplanets. We have shown that the tidal interaction between protoplanets and the nebular disk limits the final mass of a protoplanet, because of tidal truncation of gas flow onto it from the nebula.

We modeled the formation of giant planets as involving first the accumulation of a solid core by accretion of small particles (ranging in size from dust particles to comets) and then, after a critical value of the core-mass has been attained, by rapid accretion of gas from the solar nebula. We have followed the evolution of theoretical models of Uranus and Saturn to the present, and have successfully matched our theoretical models with current observations. The onset of strong winds in protostars triggers strong shock activity in regions of star formation. Our shock models have explained the associated H_2O maser activity and have predicted the strong emission of oxygen and silicon fine structure lines around protostars. The predicted silicon fine structure emission was observed from the KAO.

The major accomplishment of the theoretical work on the diffuse interstellar medium has been the completion of the first phase of a study of the history of interstellar dust grains. In this work, we have looked at the structure and grain dynamics of fast (~100 km/sec) interstellar shock waves. These supernova-driven shock waves are the dominant mechanism for destroying interstellar dust, and previous studies had derived rates which were orders of magnitude too large to reconcile with observations. By including several new physical processes in our theoretical models of these shocks, including the time-dependent drop in driving pressure and the magnetic field, we have shown that the predicted grain destruction rate is lowered by an order of magnitude.

(D. Hollenbach, Ext. 4164)

Atmospheric Evolution Studies

A one-dimensional radiative-convective model has been used to study climatic evolution on Venus, Earth, and Mars. The model predicts that Earth's atmosphere would be unstable with respect to loss of water for an increase of as little as 10% in the solar flux incident at the top, because the stratosphere would become wet, and H_2O would be destroyed by photolysis followed by escape of hydrogen to space. The critical solar flux required to trigger a runaway greenhouse (i.e., complete evaporation of the oceans) is somewhat greater – about 40% higher than the present flux at Earth's orbit. Since solar luminosity was 25 to 30% lower shortly after the planets had formed, these results imply that Venus may once have had oceans on its surface. Whether or not this was the case, Venus could have lost large amounts of water by this mechanism.

The outstanding problem for Mars and Earth is to explain how their climates could have been warmer in the past despite decreased solar luminosity. In both cases, the answer probably involves increased concentrations of atmospheric CO_2. Such concentrations of 100 to 1000 times the present could have kept Earth's mean surface temperature above freezing during the Archean era. Up to 20 bars of CO_2 could have been present during the first few hundred million years of Earth's history; this would have resulted in surface temperatures near 100°C. Much lower CO_2

levels must have been reached by the time of the glacial periods of the early and late Proterozoic. For Mars, CO_2 surface pressures of 1 to 5 bars could have produced surface temperatures above freezing. The existence of a warm, dense CO_2 atmosphere, with accompanying precipitation and runoff, early in Mars history could explain the formation of the observed valley networks.

(J. Kasting, Ext. 5233)

Analysis of Plasma Data from Near Halley's Comet

About 66 hr of tracking was provided for the Pioneer 7 spacecraft during March 18–22, 1986, when it was near Halley's comet. Data were collected from the sensitive Ames Research Center plasma analyzer during most of this time. Analysis indicates the probable presence of hydrogen from the comet's coma, picked up by the solar wind, in the vicinity of the comet nucleus (near the closest approach distance of 1.2×10^7 km). The solar windspeeds near the comet during this time were measured also; they decreased from ~400 km/sec at the beginning of the period to ~330 km/sec about 24 hr later. For the remainder of the period, the speeds remained fairly constant, although a small increase (~25 km/sec) was observed that probably was associated with a prominent disconnection of the comet's tail that has been reported.

The early part of the tracking was relatively close ($\sim 9 \times 10^6$ km) to the expected location of the comet tail axis. A brief period, then, of decreased solar wind speed and density, and increased solar wind electron temperature, may have been associated with mass loading of the solar wind by cometary ions, and with heating of the solar wind electrons at a cometary bow wave.

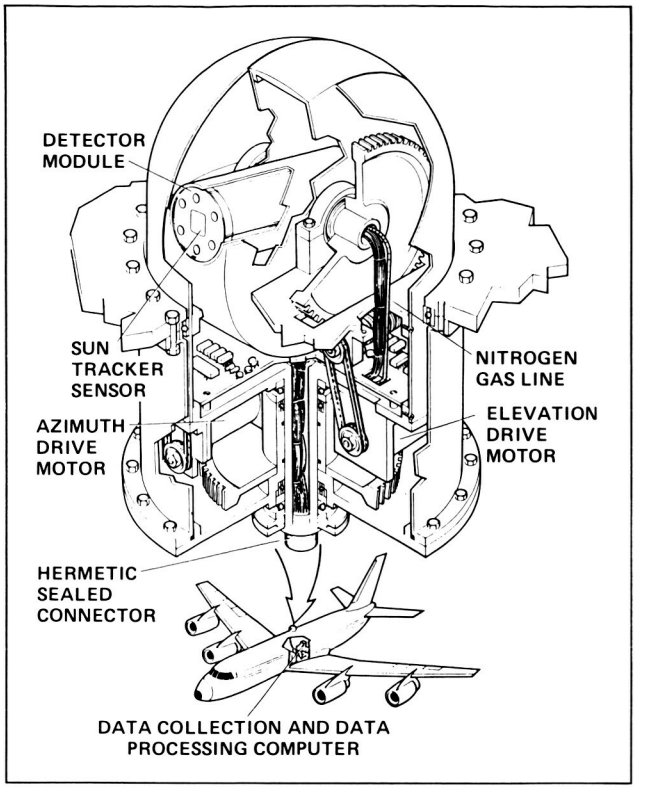
(J. Mihalov and H. Collard, Ext. 5516/6264)

An Airborne, Autotracking Sunphotometer

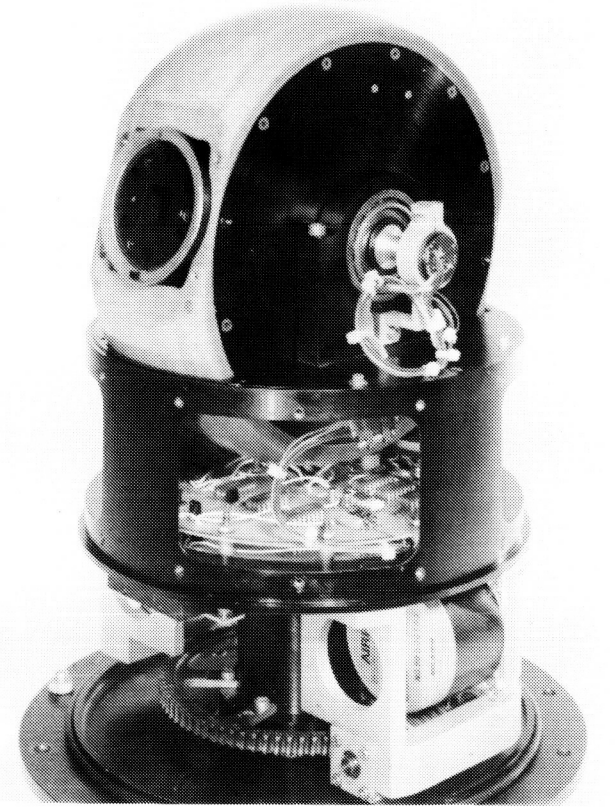
Sunphotometry has been proven a successful technique for measuring multiwavelength aerosol optical depths, and is showing a strong potential for measuring water vapor transmissions. Historically, nearly all measurements have been ground-based, yielding no information on the vertical profile of attenuation, and unable to characterize regional variations — with the exception of sunphotometer networks. In contrast, airborne sunphotometry has the potential to provide aerosol optical depths and water vapor transmissions on horizontal and vertical scales as is necessary for climate studies.

Previous airborne optical depth measurements have been limited to using hand-held photometers inside an aircraft cabin. These systems were restricted in terms of data handling and recording, not to mention accuracy, which suffered because of pointing difficulties and the dependence of the results on solar beam-window angle. In addition, tracking the Sun during spiral ascents and descents (the primary mode for obtaining vertical profile data) would require switching the internally mounted sunphotometer from window to window, a complicated procedure that would decrease data volume and introduce additional analysis problems. All these drawbacks have been overcome by the design and development of a sunphotometer that can be mounted outside the aircraft skin in a feedback-controlled active-tracking fashion.

The Ames Airborne Autotracking Sunphotometer consists of a solar tracking system, a detector module, a temperature-control system, a nitrogen purge system, the mechanical drive chain, and a data-collection system. The detector module contains six separate silicon photodetectors, each with its own replaceable narrow-band optical filter. Thus, the Sun is viewed at six independent wavelengths simultaneously. This speeds up data acquisition and allows the measurement of the optical depth of even small patches of tenuous clouds. The present time resolution is limited to 2 sec, determined by the data-acquisition rate that is synchronized with the navigational data rate. At an aircraft speed of 100 m/sec, the corresponding spatial resolution is 200 m. The current set of wavelength bands centers around 380, 450, 526, 600, 940, and 1020 nm. Aside from Rayleigh scattering, the 380- and 450-nm bands are affected by aerosols and nitrogen dioxide, the 525- and 1020-nm bands are sensing aerosols only, the 600-nm band is affected by aerosols and ozone, and the 940-nm band is situated at a water vapor absorption feature, but is also affected by aerosols. The solar tracking system is designed to be able to acquire the Sun from ±25° and to track it to an accuracy better than ±0.2°. The large field of view is required because initial pointing in manually controlled until solar acquisition occurs. It simplifies initial pointing and also allows reacquisition of the Sun if tracking is lost



Sunphotometer layout and location on CV-990



Interior view showing sunphotometer electronics, drive train, and nitrogen purge tube

because of abrupt aircraft movements or interception of an optically very thick cloud. The detector signals, detector temperature, altitude, longitude, latitude, tracking error, Sun tracker azimuth and elevation position, and Greenwich mean time are recorded on floppy disks and are printed on a printer for data backup. An HP 9816 computer is used to process the data and graphically display optical depth plots in real time.

The Ames Airborne Autotracking Sunphotometer was successfully operated on the NASA CV-990 aircraft. It is presently flown alternately on the NASA C-130 and Sandia National Laboratories' Twin Otter. Provisions have been made to install it on the NASA DC-8 aircraft.

(R. Pueschel, Ext. 5254)

An Expert System for Particle Analysis

A specific solution to a general problem that occurs in many subject areas is the identification of shapes or inhomogeneities in the presence of a pervasive background. The standard method of identification and classification is to have a human expert study some form of representation (such as pictures) of the sample and manually count and size the shapes highlighted from the pervasive background. This method is tedious and time-consuming; error can become a function of the exhaustion of the expert.

In order to increase cost effectiveness, consistency of the results, and objectivity, the structure of the problem has been matched to an automated computer solution through the cooperation of scientific and engineering personnel from the Atmospheric Experiments Branch and the Information Sciences Office.

Hardware has been assembled and configured to result in an analog-to-digital signal processor (ADSP) that converts synchronization information from a scanning electron microscope (SEM) and transforms analog picture information into discrete digital representation of the data. Signal-integration techniques improve the signal-to-noise ratio from 1:2 at the SEM to 5:1 at the digitized output of the ADSP. The data from the signal processor are streamed to the tape of an HP 1000 computer via a parallel interface. This tape is downloaded to a VAX 11/780 where it is read for classification by the software.

The system software's main components are a preprocessor, a classifier, and a set of feature extractors. The preprocessor consists of modules for format conversion, image smoothing, edge detection, and image segmentation. Object classification is done with a Lisp condition tree. Typical feature extractors are particle illumination, horizontal and vertical intensity gradients, geometric elongation, and average intensity.

Test runs on depositions of sulfuric acid droplets that were collected in the stratosphere with U-2 high-flying aircraft have shown that the expert system is comparable to a human expert at the present 89% success rate (i.e., the system correctly identifies 89% of previously classified data points). Work is in progress to improve this success rate and to make the expert system the standard method of particle size analysis.

(R. Pueschel, Ext. 5254)

0.1 K Bolometer

A working, 1-mm-continuum-bolometer detector system has been constructed for the Hale 200-in. telescope at Mount Palomar. This system uses the technique of adiabatic demagnetization to achieve operating temperatures of 0.06 to 0.1 K. The system is functional and has demonstrated the lowest noise-equivalent power (NEP) bolometer operation to date (6×10^{-17} W/Hz). This program has important implications for the SIRTF project, as there is an adiabatic-demagnetization-cooled bolometer system that has been accepted as one of the initial instrument complement.

(T. Roellig, Ext. 6426)

Composition of Saturn's Rings

Observations were made of the Saturn ring system at a wavelength of 380 μm. Two independent methods were used to derive the ring-brightness temperature at this wavelength. One of the methods, that of directly scanning the ring system, was done for the first time in this work. Both methods yielded the same ring-averaged brightness temperature, to within their derived uncertainties. The brightness temperature that was derived was 34 $\pm$7 K for the averaged A and B rings. When compared with the results obtained at other wavelengths, this shows that the brightness temperatures fall smoothly and gradually from the infrared into the radio. This can be understood in terms of the variation of the optical properties of the ring particles with wavelength. At the shorter infrared wavelengths, the observed ring brightness temperature of 90 K is indicative of the actual physical particle temperature. At these wavelengths, the ring particles have very high emissivities. At the longer radio wavelengths, the particle emissivity is very low so that the ring brightness temperatures are indicative of diffusely scattered planetary disk emission, which corresponds to approximately 8 K. Our result falls in the intermediate spectral region between these two regimes. The gradual change in ring brightness temperature implied by our results has important consequences on the ring particle composition. Our results show that pure water ice cannot explain the observed ring optical properties. Thus the presence of scattering impurities is needed.

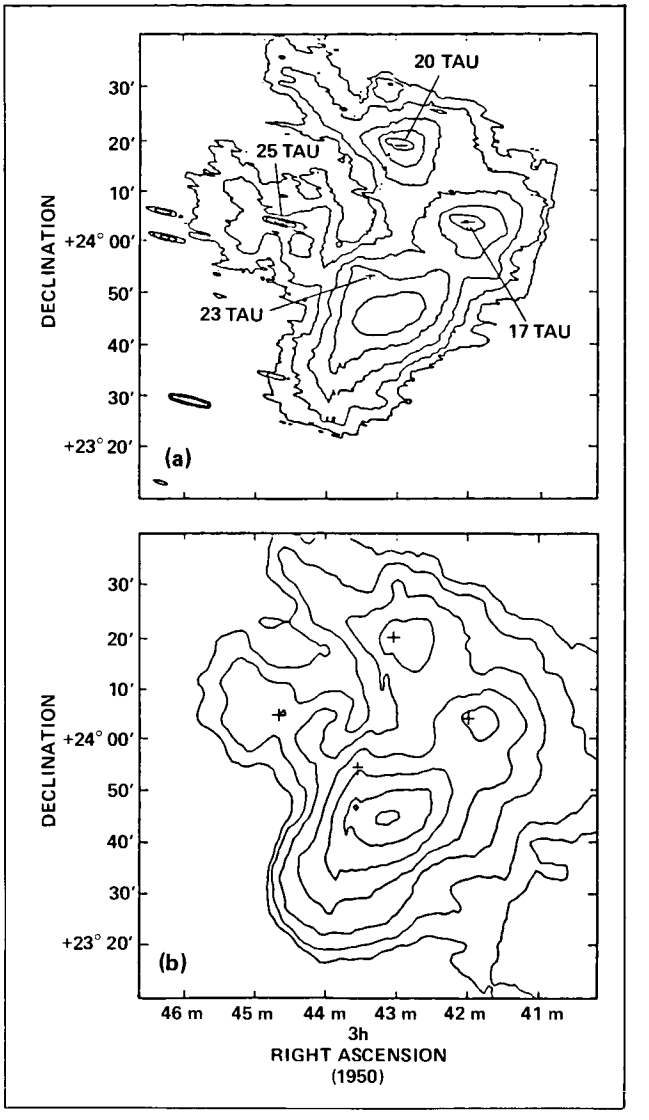
(T. Roellig, Ext. 6426)

The Properties of Interstellar Dust: Micrograins or Macromolecules?

The Infrared Astronomical Satellite (IRAS) produced the first all-sky map of the heavens at infrared wavelengths during its 1 yr in orbit in 1983. Ames Research Center played a central role in the definition and development of the telescope and cryogenic systems of this extremely successful mission. The IRAS catalogs and other data products have been released into the public domain, and many scientists with a variety of interests are pursuing research programs based on this valuable new resource.

The IRAS data provide important new information about the properties of interstellar dust grains – small particles mixed with the interstellar gas which contain most of the elements heavier than helium in the interstellar medium. An important new property of the interstellar dust discovered by IRAS is illustrated in the figure, which is based on the work of Ames scientists together with the University of Hawaii. The figure compares the distribution of infrared emission from the vicinity of the bright stars in the Pleiades cluster, as observed in two widely spaced bands centered at infrared wavelengths of 12 and 100 μm. In optical photographs, this region appears bright because clouds of interstellar dust reflect the light from the stars which shine on them. Here we see the infrared, or thermal, radiation from these same grains, which are also heated by the starlight. The significant and surprising result shown by this figure is that the region of emission is of comparable extent at the two widely spaced wavelengths. Previous ideas would have predicted that the emission at 12 μm, which comes from warmer material, would be more concentrated toward the heating stars than that at 100 μm. Further analysis of these results suggests that the 12-μm radiation comes from very small particles which contain only a few hundred atoms, or perhaps even from large molecules which are rich in carbon. The small size of these "micrograins" or "macromolecules" allows them to radiate in the 12-μm band even though they are far from the stars, because they can be excited by the absorption of only a single quantum of heating radiation.

In either case, these and other data, much of which was also obtained by Ames investigators, have demonstrated the existence of a previously unidentified component of the interstellar matter. This raises questions of interest to Ames programs in such areas as the physics of interstellar dust and the origin and dissemination of the biogenic elements. Further studies of this phenomenon will be a prime scientific objective of experiments on the Kuiper Airborne Observatory and on future facilities, such as the Space Infrared Telescope Facility.



Maps of the Pleiades cluster as observed from the IRAS satellite at infrared wavelengths of 12 (top) and 100 μm. On the 12-μm map, the positions of the bright optical stars are noted. (a) 12-μm map of the Pleiades; (b) 100-μm map of the Pleiades

(M. Werner, Ext. 5101)

Dynamics and Energetics of the Venus Ionosphere

Continuing studies of the Venus ionosphere have been expanded to include the effects of viscosity on the high-altitude ion flow from the dayside to the nightside. Our findings show that viscosity of the ion gas can be safely ignored in solving the dynamical equations because the reduction in velocity caused by viscous forces appears to be only a few percent.

The simple ionospheric model of heat transport in the Venusian ion gas has been expanded to include vertically distributed energy losses. The results so obtained are qualitatively similar to those yielded by the simple model, but the nocturnal heat source required to account for observed ion temperatures seems to be somewhat larger.

The finite-difference ion density model developed several years ago has been altered to raise the height of the ionopause from 480 to 800 km. Contrary to expectations, it was found that the nightside ion density was not very sensitive to the ionopause height. Computed nightside ion densities did rise, but only by about 20%. This behavior can be explained by noting that raising the nocturnal ion density reduces the transterminator ion velocity, thus inhibiting the rise in ion density. However, the nocturnal ionosphere is very sensitive to neutral atmospheric structure and plasma temperature, both of which strongly influence the rate of vertical ion diffusion.

These models are being extended to simulate the Martian ionosphere.

(R. Whitten, Ext. 5498)

Discoveries in Comet Halley

A 3-μm ice band was observed in Comet Halley giving the first positive evidence for the presence of water ice in this comet. Only two previous comets have been observed to have water ice. The positive identification of water ice is important for understanding the origin of comets. These observations were made at the Lick Observatory 120-in. telescope in November 1985 as Comet Halley approached Earth. These observations and interpretations were performed by NASA Ames Research Center and U.C. Santa Cruz.

Comet Halley was also observed from 5 to 10 μm with the 3-m Kuiper Airborne Observatory (KAO) on flights originating from Moffett Field, California, and Christchurch, New Zealand. These observations were made with a 5- to 13-μm multidetector spectrometer. Identified in the spectra was a strong silicate emission feature. In addition, very tight upper limits were established for many of the other emission features. These observations were performed by ARC; Planetary Science Institute, Tucson; U.C. Berkeley; and U.C. Santa Cruz.

(F. Witteborn, Ext. 5520)

Analysis of Spacelab 2 Infrared Telescope Data

Analysis of Spacelab 2 infrared telescope (IRT) data tapes by J. Simpson and F. Witteborn in collaboration with a team led by G. Fazio , Center for Astrophysics, Cambridge, MA, has provided information on the Shuttle contaminant environment. Water column densities of about 10^{13} cm^{-2} were measured. Particulate sighting rates on the order of 7 per minute were determined with sizes ranging from 50 to 300 μm and temperatures from 180 to 310 K. Further work continues to characterize the Shuttle particle environment. Preliminary results were reported at the 1986 COSPAR meeting.

(F. Witteborn, Ext 5520)

Dynamical Studies of the Venus Atmosphere

The possible influence of surface topography on atmospheric motions between the surface and middle cloud region is being investigated. Motivation for the work comes from the apparent influence of the mountainous region known as Aphrodite on vertical wind fields which was encountered by one of the VEGA Mission balloons as it flew over these mountains at an altitude of 54 km. Vertical winds were enhanced, reaching amplitudes over 2 m/sec, with downdrafts lasting about an hour. The mechanism by which surface terrain influences the atmosphere at high altitudes involves gravity waves generated at the planet surface which subsequently propagate to high altitudes. Whether or not surface-generated waves are able to reach upper atmospheric levels depends on the background wind and temperature structure

of the atmosphere. Calculations using a multidimensional gravity wave model show that certain waves are capable of propagating from the surface to high altitudes. The complicated nature of the difference between the vertical lapse rate of temperature and the adiabatic lapse rate, combined with the unusual Venus wind field, causes resonances to occur which produce amplification of the waves as they propagate upward. Under certain conditions, the upward propagating waves have similar vertical wind amplitudes and periods as observed by the VEGA balloons. Future modeling work will assess the effects of the upward moving waves on the mean atmospheric wind and temperature fields.

(R. Young, Ext. 5521)

Dynamical and Transport Studies of the Earth's Middle Atmosphere

A three-dimensional, primitive-equation circulation model is being used to study several aspects of the dynamic meteorology of the terrestrial middle atmosphere. Results to date have shown that intermediate-scale cyclone waves, which are generated in the troposphere, force planetary-scale waves which become the dominant wave modes in the stratosphere. Wave-wave interactions among the intermediate scale modes are responsible for the planetary wave forcing. This planetary wave-generating mechanism is found to be much more important for eastward traveling waves than any other mechanism that has previously been considered. The nonlinear forcing seems capable of accounting for certain features observed in eastward traveling waves in the southern hemisphere (for instance, the lack of coherence between the troposphere and stratosphere observed for the largest planetary wavelengths).

Work is in progress to model the dispersal of the El Chichon volcanic aerosol cloud which was injected into the lower stratosphere near the equator in 1982. The computed effects of the aerosol cloud on stratospheric wind and temperature fields, together with the rate at which the cloud moved poleward in both hemispheres, will be compared to aircraft and satellite measurements of cloud and meteorological variables. Results from this research will help to define important transport processes in the stratosphere, as well as determine the climatic impact of volcanic eruptions.

(R. Young, Ext. 5521)

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16. Abstract

This report describes various research and technology activities at Ames Moffett and Ames Dryden. Highlights of these accomplishments indicate the Center's varied and highly productive research efforts for 1986.

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